THREE DIMENSIONAL MUSCULOSKELETAL MODELLING OF THE CHEST PRESS RESISTANCE EXERCISE FOCUSING ON THE BIOMECHANICAL AND ANTHROPOMETRIC CONSIDERATIONS OF THE END-USER

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The aim of this study was to evaluate whether three dimensional (3D) musculoskeletal modelling could be effective in assessing the safety and efficacy of exercising on a chest press resistance training machine. Three anthropometric cases were created; these represented a 5th percentile female as well as a 50th and 95th percentile male based on body mass index (BMI). The results indicate that adjustments had to be made to the default model in order to solve the forward dynamics simulations using recorded joint angulations during the inverse dynamics simulations. The anthropometric dimensions of the end-users appeared to be adequately accommodated by the chest press's engineered or manufactured adjustability. It did not appear as if the exercise put undue strain on the spinal structures when exercised with correct positioning and technique at an appropriate resistance.

KEYWORDS: LifeModelerTM, simulation, training.

INTRODUCTION: The aim of this study was to evaluate whether three dimensional (3D) musculoskeletal modelling could be effective in assessing the safety and efficacy of exercising on a chest press resistance training machine. The focus of the evaluation was on biomechanical and anthropometric considerations of the end-user.

METHODS: A 3D musculoskeletal full body model was created using LifeModeler™ software and incorporated into a multibody dynamics model of the chest press resistance exercise machine modelled in MSC ADAMS. The LifeModeler™ software runs as a plug-in on the MSC ADAMS software. LifeModelerTM software has previously been used in studies in the fields of sport, exercise and medicine (Agnesina & al., 2006; Nolte, Krüger, & Els, 2011).Three anthropometric cases were created; these represented a 5th percentile female as well as a 50th and 95th percentile male based on body mass index (BMI). Resistance on the chest press machine was set at fifty percent of the functional strength one repetition maximum (1RM) for each anthropometric case, two repetitions were performed (Table 1).
The following steps were performed in order to ensure realistic kinematics during the inverse dynamics simulations: 1) Positioning of the human model on the exercise equipment, 2) Adjustment of the posture to allow for the human machine interface to be created, 3) Creating the constraints between the human and machine, 4) Prescribing the motion of the repetitions, 5) Evaluation of the resultant kinematics, 6) Adjustment of joint positions until inverse dynamics resulted in a realistic exercise movement. Bushing elements were used to secure the lower torso to the seat as well as the neck to the back rest and spherical joints were used to connect the hands to the handle bars of the chest press machine.
The inverse dynamics – forward dynamics method was applied during the simulations. Inverse dynamics simulations are performed on models which are being manipulated by the use of motion agents or motion splines. During the inverse dynamics simulation, a rotational motion was applied to the revolute joint of the lever arm attached to the handle bars of the chest press machine in order to generate the required movement of the resistance training machine. This movement replicated the pulling (concentric) and resisting (eccentric) phase of the exercise. The time for the concentric phase was set at 1.66 seconds and the eccentric phase longer at 3.33 seconds to mimic conventional resistance training technique in which

the downward phase is more deliberate to prohibit the use of momentum. The 1.66 second concentric phase included a STEP function approximation over 0.5 seconds to ensure a gradual start to the movement. The joints forces of the model were recorded during the inverse dynamics simulation in order to calculate the changes in joint torques to result in the required machine movement (Figure 1).
After the inverse dynamics simulation was performed, the rotational motion was removed from the rotational joint of the lever arm of the chest press machine. The resulting joint movements were then used to drive the model during the forward dynamics simulation in the manner as developed through the inverse dynamics simulation.

Table 1
User population strength data (RSA-MIL-STD, Vol 5, 2001).

User population group	User population group exercise resistance (50% 1RM) kg
5th percentile female	7
50th percentile male	19
95th percentile male	35

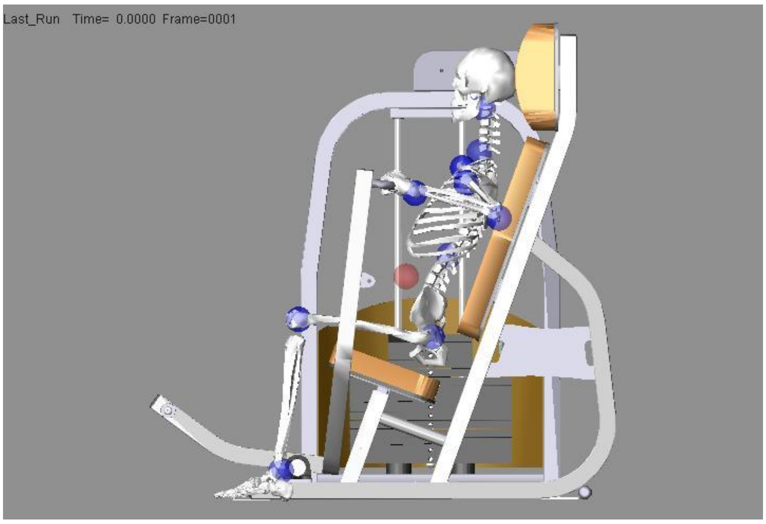

Figure 1: 3D musculoskeletal modelling of the chest press resistance training machine and 95th percentile male musculoskeletal model using LifeModeler™ and MSC ADAMS software.

RESTULTS: The results indicate that adjustments had to be made to the default model in order to solve the forward dynamics simulations using recorded joint angulations during the inverse dynamics simulations. As a result no muscle (force and contraction) results could be obtained which negatively impacted the value of the modelling in evaluating the chest press exercise. Peak wrist torque values in comparison with the other joints were the highest for all the cases studied except the 95th percentile male (Table 2). In all the anthropometric cases the peak thoracic compression forces were the lowest, followed by the peak lumbar compression forces and the highest peak compression forces were recorded in the cervical spine (Table 3).

Table 2
Right wrist, elbow and shoulder torque (Nm) results in the sagittal plane for the 3 anthropometric cases.

Musculoskeletal model	Joint	Mean (Nm)	Min.	Max.
5th percentile female	Wrist	1.3	-1.3	6.5
	Elbow	4.2	0.0	6.1
	Shoulder	0.7	0.0	1.1
50th percentile male	Wrist	0.8	-0.2	3.3
	Elbow	1.0	-0.7	2.3
	Shoulder	1.0	0.0	1.2
95th percentile male	Wrist	3.1	-6.8	2.7
	Elbow	2.0	-0.2	2.9
	Shoulder	1.8	-0.2	3.0

Table 3
Cervical, thoracic and lumbar spine joint compression forces (N) for the 3 anthropometric cases. Note: positive values indicate forces in a superior direction and negative values indicate forces in an inferior direction.

Musculoskeletal model	Spinal joint	Mean (N)	Min.	Max.
5th percentile female	Cervical spine	-486.3	-590.2	-372.0
	Thoracic spine	100.3	79.4	149.1
	Lumbar spine	145.0	124.1	193.8
50th percentile male	Cervical spine	-467.1	-538.0	-329.0
	Thoracic spine	140.0	113.7	168.1
	Lumbar spine	200.0	173.2	227.6
95th percentile male	Cervical spine	852.5	1248	474.0
	Thoracic spine	-32.7	-97.1	162.8
	Lumbar spine	28.2	-36.1	223.9

DISCUSSION: The anthropometric dimensions of the end-users appeared to be adequately accommodated by the chest press's engineered or manufactured adjustability. The LifeModeler™ default model was not adequate to solve the forward dynamics simulations for any of the anthropometric cases. Possible reasons for this could include the degrees of freedom involved in a multi joint exercise involving highly mobile joints such as the shoulder. Furthermore it could be that additional musculature is required to provide more stability in the shoulder joint during the forward dynamics simulations.
Joint torque values obtained for the wrist, elbow and shoulder appear to be plausible when comparing the values to peak values obtained by means of isokinetic testing at 60 degrees per second. For example, wrist flexion/extension values of 13.8 Nm and 12.7 Nm respectively in non-disabled subjects (Van Swearigen, 1983). Elbow flexion/extension values of 36 Nm for both elbow flexion and extension in female college basketball players (Berg, Blank, & Muller, 1985) and shoulder flexion/extension values of 77 Nm and 53 Nm for males and 38 Nm and 24 Nm for females respectively in a group of non-disabled (Nicholas, Robinson, Logan, & Robertson, 1989). Joint torque values for the three joints evaluated were much lower than values obtained during peak isokinetic testing however it is important to bear in mind that the values obtained in this study were not from maximal testing such as the isokinetic testing. The peak wrist joint torque was the highest recorded value for all the joints in the anthropometric cases except the 95th percentile male which indicate the important role the wrist plays in the chest press or similar pushing movements.
Although pushing activities can pose a potential risk for spine injuries (Knapik & Marras, 2009) it did not appear as if the exercise put undue strain on the spinal structures when exercised with correct positioning and technique at an appropriate resistance. However, the wrist joint and cervical spine appear to be vulnerable areas during the chest press exercise due to the relatively high wrist torque values in comparison to other joints as well as the relatively high cervical compression loads recorded.

CONCLUSION: Adjustments had to be made to the default model in order to solve the forward dynamics simulations using recorded joint angulations during the inverse dynamics simulations. As a result no muscle (force and contraction) results could be obtained which negatively impacts the value of the modelling in evaluating an exercise. The anthropometric dimensions of the end-users appeared to be adequately accommodated by the chest press's engineered or manufactured adjustability. Although pushing activities can pose a potential risk for spine injuries it did not appear as if the exercise put undue strain on the spinal structures when exercised with correct positioning and technique at an appropriate resistance. However, the wrist joint and cervical spine appear to be vulnerable areas during the execution of the chest press exercise due to the relatively high wrist joint torques produced in comparison to other joints as well as the reasonably high cervical compression loads recorded for the three anthropometric cases. 3D musculoskeletal modeling is certainly the way of the future and with the developments and improvements that are continually being made will probably form a major role in the design of most types of equipment.

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