3/8/2016 **Overview of updates to the model and modeling environment**

In our prior publication (Saul KR, Hu X, Goehler CM, Daly M, Vidt ME, Velisar A, Murray WM. Benchmarking of dynamic simulation predictions in two software platforms using an upper limb musculoskeletal model. Computer Methods in Biomechanics and Biomedical Engineering. 2015; 18:1445-58), we described simulations performed in the OpenSim modeling platform and compared these results to simulations run using a comparable model in the SIMM-Dynamics Pipeline-SD/Fast environment. In that study, we illustrated that differences in algorithmic implementation in these two software platforms widely used by the biomechanics community for the simulation of movement can affect simulation predictions. Specifically, we demonstrated the most substantial divergence arose from different implementations of muscle paths and force generation in the two software platforms. At the time of publication, the two software platforms (specifically, OpenSim 2.4 and SIMM version 4.2.1, Dynamics Pipeline, version 3.3, SD/Fast version B.2.8) used different algorithms to calculate muscle moment arm for muscle paths that included moving muscle points (Sherman et al. 2013). In addition, OpenSim did not enable moving points defined to exist only within a specified range of motion; the biceps actuators in the SIMM model each had a single point of this type. These differences between platforms led to the most substantial differences in simulation results between platforms.

**Revisions to OpenSim and the model.** Since publication, substantial changes were made to the OpenSim environment in release 3.2 and later releases that pertain to the calculation of moment arm and the handling of moving points. Thus, we have revisited both the model and the simulation results for compatibility with the most recent implementation of OpenSim and comparisons between platforms. Specifically, OpenSim now uses the same algorithm as SIMM to calculate muscle moment arm when paths include moving muscle points. Based on this change, muscle paths and tendon slack lengths that were altered to accommodate the moment arm calculation in OpenSim v2.4 were restored to match those implemented for the same muscles in SIMM. (See summary tables) Thus, these aspects of the model are now identical between platforms.

As an additional new difference between platforms, OpenSim no longer permits moving muscle points for which the motion depends on two separate coordinates. The biceps (short and long head) included moving muscle points of this type. In addition, the scaling tool in OpenSim does not natively scale any joints that have translations; one joint of this type was used to accommodate the complex movement of the middle deltoid and allow dependence on multiple coordinates. To address these issues and allow this model to be used in later versions of OpenSim, we have replaced the moving points in question with new points that depend only on a single coordinate (forearm rotation for biceps and shoulder elevation for deltoid). Finally, the single biceps moving point that was defined to exist only within a specified range of motion was removed. These changes result in implementation that remains different between SIMM and OpenSim.

**Simulation benchmarking.** New simulations using the revised model have been performed to elucidate the effect of the platform and model upgrade, and to provide new benchmarking data for the community. In brief, the revisions have reduced the effects of muscle model and computational differences between platforms, but the sensitivity of optimization-driven simulations to the specific platform and model persist, as expected. These results and models have been released for public use. These platform revisions highlight the utility of a benchmarking dataset to allow for model development and interpretation in the context of new software and software upgrades.

**Summary of model and tutorial updates and parameter tables**

Model changes pertain to tutorial modules 2-7 which use a partial model in gravity-driven forward simulations and the full model in gravity-driven forward simulations, EMG-driven simulations, scaling and inverse kinematics processing, CMC analysis, and CMC-driven forward dynamic simulations. There is one new partial model (MoBL\_ARMS\_module3\_samemuscles). There are three different versions of the new full model: one without torso rotation and translation (MoBL\_ARMS\_module2\_4\_all\_muscles), one with torso rotation and translation (MoBL\_ARMS\_module5\_scaleIK), and one with torso rotation only about the z axis (MoBL\_ARMS\_module6\_7\_CMC). These versions of the model are named according to which simulation they are be used with and names correspond with names in the tutorial document.

See tables for summary of force-generating parameters (Table 1) and changes to muscle paths (Table 2).

**Table 1: Force-generating parameter table.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Muscle** | **Abbrev** | **Optimal Fiber Length (cm)** | **Peak Force (N)** | **Tendon Slack Length (cm)** | **Pennation Angle (o)** |
| ***Shoulder*** |  |  |  |  |  |
| Deltoid |  |  |  |  |  |
| Anterior | DELT1 | 9.8 | 1218.9 | 9.3 | 22 |
| Middle | DELT2 | 10.8 | 1103.5 | 11 | 15 |
| Posterior | DELT3 | 13.7 | 201.6 | 3.8 | 18 |
| Supraspinatus | SUPRA | 6.8 | 499.2 | 4 | 7 |
| Infraspinatus | INFRA | 7.6 | 1075.8 | 3.1 | 19 |
| Subscapularis | SUBSCAP | 8.7 | 1306.9 | 3.3 | 20 |
| Teres minor | TMIN | 7.4 | 269.5 | 7.1 | 24 |
| Teres major | TMAJ | 16.2 | 144 | 2 | 16 |
| Pectoralis major |  |  |  |  |  |
| Clavicular | PECM1 | 14.4 | 444.3 | 0.3 | 17 |
| Sternal | PECM2 | 13.8 | 658.3 | 8.9 | 26 |
| Ribs | PECM3 | 13.8 | 498.1 | 13.2 | 25 |
| Latissimus dorsi |  |  |  |  |  |
| Thoracic | LAT1 | 25.4 | 290.5 | 12 | 25 |
| Lumbar | LAT2 | 23.2 | 317.5 | 17.7 | 19 |
| Iliac | LAT3 | 27.9 | 189 | 14 | 21 |
| Coracobrachialis | CORB | 9.3 | 208.2 | 9.7 | 27 |
| ***Elbow*** |  |  |  |  |  |
| Triceps |  |  |  |  |  |
| Long | TRIlong | 13.4 | 771.8 | 14.3 | 12 |
| Lateral | TRIlat | 11.4 | 717.5 | 9.8 | 9 |
| Medial | TRImed | 11.4 | 717.5 | 9.1 | 9 |
| Anconeus | ANC | 2.7 | 283.2 | 1.8 | 0 |
| Supinator | SUPRA | 3.3 | 379.6 | 2.8 | 0 |
| Biceps |  |  |  |  |  |
| Long | BIClong | 11.6 | 525.1 | 27.2 | 0 |
| Short | BICshort | 13.2 | 316.8 | 19.2 | 0 |
| Brachialis | BRA | 8.6 | 1177.4 | 5.4 | 0 |
| Brachioradialis | BRD | 17.3 | 276 | 13.3 | 0 |
| ***Major wrist or forearm*** |  |  |  |  |  |
| Extensor carpi radialis longus | ECRL | 8.1 | 337.3 | 24.4 | 0 |
| Extensor carpi radialis brevis | ECRB | 5.9 | 252.5 | 22.2 | 9 |
| Extensor carpi ulnaris | ECU | 6.2 | 192.9 | 22.9 | 4 |
| Flexor Carpi radialis | FCR | 6.3 | 407.9 | 24.4 | 3 |
| Flexor capri ulnaris | FCU | 5.1 | 479.8 | 26.5 | 12 |
| Palmaris longus | PL | 6.4 | 101 | 26.9 | 4 |
| Pronator teres | PT | 4.9 | 557.2 | 9.8 | 10 |
| Pronator quadratus | PQ | 2.8 | 284.7 | 0.5 | 10 |
| ***Wrist/hand muscles*** |  |  |  |  |  |
| Flexor digitorum superficialis |  |  |  |  |  |
| Digit 5 | FDSL | 5.2 | 75.3 | 33.9 | 5 |
| Digit 4 | FDSR | 7.4 | 171.2 | 32.8 | 4 |
| Digit 3 | FDSM | 7.5 | 258.8 | 29.5 | 7 |
| Digit 2 | FDSI | 8.4 | 162.5 | 27.5 | 6 |
| Flexor digitorum produndus |  |  |  |  |  |
| Digit 5 | FDPL | 7.5 | 236.8 | 28.2 | 8 |
| Digit 4 | FDPR | 8 | 172.9 | 29.2 | 7 |
| Digit 3 | FDPM | 8.4 | 212.4 | 30.3 | 6 |
| Digit 2 | FDPI | 7.5 | 197.3 | 30.2 | 7 |
| Extensor digitorum communis |  |  |  |  |  |
| Digit 5 | EDCL | 6.5 | 39.4 | 33.5 | 2 |
| Digit 4 | EDCR | 6.3 | 109.2 | 36.5 | 3 |
| Digit 3 | EDCM | 7.2 | 94.4 | 36.5 | 3 |
| Digit 2 | EDCI | 7 | 48.8 | 36.5 | 3 |
| Extensor digiti minimi | EDM | 6.8 | 72.4 | 33.5 | 3 |
| Extensor indicis propius | EIP | 5.9 | 47.3 | 21 | 6 |
| Extensor pollicis longus | EPL | 5.4 | 88.3 | 23.1 | 6 |
| Extensor pollicis brevis | EPB | 6.8 | 46 | 11.6 | 7 |
| Flexor pollicis longus | FPL | 5.5 | 201 | 19.7 | 7 |
| Abductor pollicis longus | APL | 7.1 | 116.7 | 13 | 8 |

**Table 2: Summary of changes to muscle path points**. Notes: Delt2-P2 was originally attached to Delt2pt2a and depended on shoulder rotation, and is now attached to clavicle and depends on shoulder elevation. Both Biclong-P9 and Bicshort-P6 Y spline originally depended on elbow flexion and now depend on pronation supination. Conditional path points Biclong-P10 and Bicshort-P7 were removed.

