AN APPROACH TO AN EMG-DRIVEN SUBJECT SPECIFIC MUSCULOSKELETAL MODEL OF ELBOW FLEXION
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SUMMARY
To assign muscular activation patterns to the effectively performed motion, a musculoskeletal model has been implemented. Thereby the model incorporates a subject specific scaled rigid body model of the skeletal upper extremity. The musculotendon part as such has been modeled as a hill-type chain of contractile elements, along with parallel elements which are assembled to model the elastic behavior of human’s muscular tissue. Within three equilibrium equations, depending on the elbow angle, the theoretical required muscular forces for specific angles are calculated. In addition electromyographic and anthropometric data of isometric measurements are combined with the theoretically calculated muscle forces to define a patient specific characteristic curve of the EMG–force relationship. So, a muscular activation can be generated by recorded and processed EMG data.

INTRODUCTION
Models of the human locomotor system contribute to the progress of understanding physiological as well as patho-physiological motion patterns. At that point, models enable to derive consolidated findings on the cause and effect of performed motion. So far, kinematics of the whole system are examined with movement analysis techniques, while the activation of muscles, deduced from Electromyography. The kinematic information has to be combined with the information about the muscular activation in order to subsequently evaluate biomechanical performance of muscular coordination.

METHODS
In this work, subject specific modeling of the upper extremity is conducted without the need of time intensive pre-measurements. Via a 3-dimensional optoelectronical movement analysis system, the three dimensional position of markers attached on six anatomical landmarks (acromion, epicondyle lateral, epicondyle medial, radial styloid process, ulnar process, olecranon) are used to scale a subject specific model. All relevant points of the model like muscles insertions and origins, which cannot be palpated and consequently recorded, are calculated from these anatomical landmarks. As a result, all rotation centers of the joints as well as all muscles sites of insertion and origin of the flexors and extensors (M. biceps brachii, M. brachialis, M. triceps brachii) can be defined with reference to Veegers cadaver study [1], see Figure 1.

Subsequently to the skeletal model, muscular components are included to induce movement of the whole system. Thereby the muscular modeling strategy must embrace an active part to be externally controlled, as well as a passive part. In the model, the core structures are the muscular compartments, which contract in response to an external signal. Thereby, the implemented muscular model integrates a Hill-type modeling approach into a mechanical scaffold, comprising a chain of contractile elements, as well as passive elastic components and tendons transmitting the contraction onto the bones [2]. The described musculoskeletal model is activated by processed EMG signals. Consequently activation of the described musculoskeletal model accompanies a transformation strategy to model the electromechanical coupling, hence to convert electrical signals to force inputs [3].

For that purpose a series of surface EMG signals in different static elbow angle positions are recorded. Through the exact position of recorded segment markers relative to the computed elbow joint center, all angle positions are subsequently analyzed to accurately reconstruct the elbow position. Additionally three equilibrium equations are derived as a function of elbow angles, which include all muscular forces as well as external forces, such as load of the forearm or additional load forces carried at the hand, see Figure 2.
Three equilibrium equations are derived as a function of joint angle $\theta$. Three angles, spanned between triangles of muscle and bone segments ($\alpha$ for brachioradialis, $\beta$ for biceps, $\gamma$ for triceps with WC (wrist center) and SC (shoulder center)) correlate to the overall $\theta$ and define the line of action of each muscle. Beside the sum of force contribution in x- and y-direction, all torques around the elbow equals zero because of the static allow position thus enabling to solve for the magnitude of $F_{BI}$, $F_{TR}$, $F_{BRA}$, where $l_{ua}$ and $l_{fa}$ are the length of the upper and the forearm.

$$\sum F_x = 0$$
$$\sum F_y = 0$$
$$\sum M = 0$$

This results in subject specific characteristic curves for different joint angles, which give the relation between EMG amplitudes and the corresponding contraction forces of each muscle. In short, the characteristic curve enables to transform EMG amplitude signals to force values, which are subsequently combined with percentaged force-length relation of the muscles to include the force generation capacity dependent on muscle length as function of joint angle.

**RESULTS AND DISCUSSION**

For an example validation purpose EMG-force characteristic curve has been derived for the biceps muscle from 14 isometric measurements of elbow flexion. The biomechanical connections are used to derive the percentaged force capacity by utilizing the anatomical force-length features of the muscles; whereas the determined characteristic curve enables to compute force levels deduced from EMG inputs. To determine the characteristic curve, recorded EMG amplitudes are combined with the theoretically computed force levels from the equilibrium equations for each angle position. Combining the observed results concerning force-length and EMG-force relations, transformation of input signals of the M. biceps brachii can be conducted. Finally the product of both courses yield to the required force input signal of the biceps muscle for an elbow flexion movement, see Figure 3.

**CONCLUSION**

The derived characteristic curve is able to reconstruct from a processed and transformed EMG signal in combination with theoretically calculated force level and the anatomical force-length relation to a proper force input for an activation of the muscular compartments.

In essence, the implemented subject specific musculoskeletal model clearly enables combination of EMG and movement analysis data to simulate flexion movement of the elbow joint.

**REFERENCES**