Biomechanics, kinematics, kinetics

Biomechanics is the science concerned with the internal and external forces acting on the human body and the effects produced by these forces.

Kinematics is the branch of biomechanics concerned with the study of movement from a geometrical point of view.

Kinetics is the branch of biomechanics concerned with what causes a body to move the way it does.
Some variables and parameters can be measured

- Anthropometric parameters
- Segmental kinematics (stereophotogrammetry, wearable sensors, etc)
- External forces and moments (dynamometry, baropodometry, etc)
- Muscular electrical activity (electromyography)
- Metabolic energy (indirect calorimetry)
The estimable quantities

- Instantaneous bone pose
  *(virtual representation of the skeletal system in motion)*
- Relative movement between adjacent bones
  *(joint kinematics)*
- Forces transmitted by muscles-tendons-ligaments-bones
  *(joint kinetics)*
- Muscular mechanical work/power
  system energy variation
  *(joint energetics)*

**INSTANTANEOUS 3D BONE POSE**

In order to describe the pose of the bone as a rigid body
we assume a local reference frame such that the local coordinates
of the bone points are time invariant.
The problem is now the mathematical description of the position and orientation of the local reference frame with respect to the global one.

**The description of the pose**

**Numerical description of the pose vs time (3-D case)**

Six scalar quantities in each sampled instant of time

- Position vector:
  \[ \mathbf{t}_j = [t_{txj}, t_{tyj}, t_{tzj}] \quad j = 1, \ldots, k \]

- Orientation vector:
  \[ \mathbf{\theta}_j = [\theta_{txj}, \theta_{tyj}, \theta_{tzj}] \quad j = 1, \ldots, k \]

- Orientation matrix:
  \[ \mathbf{R}_j \quad j = 1, \ldots, k \]
The orientation matrix of the local frame with respect to the global one is defined by:

1st column \( x_i \) axis versor components
2nd column \( y_i \) axis versor components
3rd column \( z_i \) axis versor components

These components are the cosines of the angles between each versor and the XYZ global axes.

**JOINT KINEMATICS**
Anatomical planes and axes

- **Sagittal plane**
- **Transverse plane**
- **Frontal (coronal) plane**

**Hip flexion-extension**

- **Flexion (+)**
- **Extension (-)**
Knee flexion-extension

Flexion (-)  Extension (+)

θ_a

θ_g

Ankle dorsal and plantar flexion

Dorsal flexion (+)

Neutral position

Plantar flexion (-)
A lower limb model

Hypotheses:
- Planar motion (sagittal plane)
- Joints are modelled using cylindrical hinges (1 dof)

Joint centres:
H Hip
K Knee
A Ankle
M Metatarsus-phalanx V toe

Experimental protocol

Joint centres:
H greater trochanter
K lateral femoral epicondyle
A lateral malleolus
M metatarsus-phalanx V toe
Flexion-extension angles of the lower limb joints during walking

\[ \theta_h, \theta_k, \theta_a \]

- Hip (\( \theta_h \))
- Knee (\( \theta_k \))
- Ankle (\( \theta_a \))

Motor task classification

- **Salita di un Gradino**
- **Alzata da una Sedia**
- **Inizio del Passo**

Fig. 4 - Registrazione degli angoli dei tre segmenti corporei (tronco, coscia e gamba) durante lo svolgimento di tre atti motori complessi.
The description of 3-D joint kinematics

1) starts from the knowledge, in each sampled instant of time, of the pose of the bony segments involved in the laboratory frame.

2) entails the estimation of the instantaneous pose (position and orientation) of one bony segment relative to the other.

Motion capture provides these data

$^i \mathbf{p}_j = [^i \mathbf{p}_{q}, ^i \mathbf{p}_{r}, ^i \mathbf{p}_{s}]$, $j = 1, ..., k$

$^i \mathbf{t}_j = [^i t_{r}, ^i t_{y}, ^i t_{z}]$, $j = 1, ..., k$

$^i \mathbf{\theta}_j = [^i \theta_{r}, ^i \theta_{y}, ^i \theta_{z}]$, $j = 1, ..., k$

$^i \mathbf{R}_j$, $j = 1, ..., k$
Relative pose

In any given instant of time:

Femur

- Global position vector: \( \tilde{\mathbf{r}}_{p} = [\tilde{r}_{px} \ \tilde{r}_{py} \ \tilde{r}_{pz}] \)
- Global orientation matrix: \( \tilde{\mathbf{R}}_{p} \)

Tibia

- Global position vector: \( \tilde{\mathbf{r}}_{d} = [\tilde{r}_{dx} \ \tilde{r}_{dy} \ \tilde{r}_{dz}] \)
- Global orientation matrix: \( \tilde{\mathbf{R}}_{d} \)

\[ \tilde{\mathbf{r}}_{p} \] \[
\tilde{\mathbf{R}}_{p} \] \[
\tilde{\mathbf{r}}_{d} \] \[
\tilde{\mathbf{R}}_{d} \]

Relative position vector & relative orientation matrix

Relative position

In any given instant of time:

Femur

- Global position vector: \( \tilde{\mathbf{r}}_{p} = [\tilde{r}_{px} \ \tilde{r}_{py} \ \tilde{r}_{pz}] \)
- Global orientation matrix: \( \tilde{\mathbf{R}}_{p} \)

Tibia

- Global position vector: \( \tilde{\mathbf{r}}_{d} = [\tilde{r}_{dx} \ \tilde{r}_{dy} \ \tilde{r}_{dz}] \)
- Global orientation matrix: \( \tilde{\mathbf{R}}_{d} \)

Relative position vector in the proximal frame

\[ \tilde{\mathbf{r}}_{pd} = \tilde{\mathbf{R}}_{p} \tilde{\mathbf{r}}_{d} - \tilde{\mathbf{R}}_{p} \tilde{\mathbf{r}}_{p} \]
Relative orientation

In any given instant of time:

\[
\begin{align*}
\mathbf{R}_{cp} \quad \text{global position matrix} & \quad \mathbf{R}_{cd} \\
\mathbf{gR}_{cp} & \quad \mathbf{gR}_{cd}
\end{align*}
\]

The two systems of reference are assumed to be aligned, then the distal system of reference moves in its new position, and then it rotates in its new orientation.

In summary
At the time $t_1$, at the time $t_2$, and so forth. Motion is described as the ensemble of the positions and orientations of the distal bone with respect to the proximal bone determined in sampled instants of time during the observation interval.

<table>
<thead>
<tr>
<th>In summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the time $t_1$, motion is described as the ensemble of the positions and orientations of the distal bone with respect to the proximal bone determined in sampled instants of time during the observation interval.</td>
</tr>
</tbody>
</table>

Orientation matrix of the distal relative to the proximal cluster frame:

$$\alpha R_{od} = \begin{bmatrix}
\cos \theta_{x'dx} & \cos \theta_{y'dy} & \cos \theta_{z'dz} \\
\cos \theta_{x'dy} & \cos \theta_{y'dy} & \cos \theta_{z'dz} \\
\cos \theta_{x'dz} & \cos \theta_{y'dz} & \cos \theta_{z'dz}
\end{bmatrix}$$

This matrix, and the three independent scalar quantities embedded in it, completely describe the orientation of the distal relative to the proximal bone. However, the relevant scalar components have no physical meaning and, as such, do not convey readable information about joint rotation.
Orientation

The orientation vector of the distal relative to the proximal cluster frame is given by

\[ \mathbf{n}_{cd} = \cos \theta_{cd} \mathbf{x}_d - \sin \theta_{cd} \mathbf{y}_d \]

This vector, and the three independent scalar quantities embedded in it, completely describe the orientation of the distal relative to the proximal bone.

However, the relevant scalar components have no physical meaning as such.

Problem

Relative position and orientation descriptions illustrated so far carry all the necessary information relative to joint kinematics, but have no direct use in movement analysis.
Orientation

The orientation of the distal relative to the proximal cluster frame may be described using a sequence of three rotations about selected axes (Euler Angles).

These rotations have a physical meaning, Nevertheless, still represent an abstraction!

Example: hip joint
Example: hip joint

Starting orientation

Orientation at time t'

First rotation: flexion-extension

Rotation about the axis $z_{d1}$: femur or pelvis medio-lateral axis
Second rotation: abduction-adduction

Rotation about the axis $x_{d2}$: femur antero-posterior axis

Second rotation: internal-external rotation

Rotation about the axis $y_{d2}$: femur longitudinal axis
In summary

A generic orientation of a distal relative to a proximal frame may be obtained as a result of three successive and ordered rotations about two or three different axes (belonging to either frames).

The three angles of the rotation sequence

\[ \alpha, \beta, \gamma \]

depend on both

- the axes about which the rotations are made to occur
- the relevant sequence

---

The Cardan convention

The rotation sequence illustrated previously provides angles that are often referred to as Cardan Angles*.

A question

What happens if the rotation sequence is changed?

Given an orientation of the distal relative to the proximal frame,

depending on the sequence selected the following descriptions are obtained:

<table>
<thead>
<tr>
<th>deg</th>
<th>yxz</th>
<th>xyz</th>
<th>zyx</th>
<th>xyz</th>
<th>yzx</th>
<th>zxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.6</td>
<td>19.4</td>
<td>10.0</td>
<td>0.6</td>
<td>1.3</td>
<td>10.0</td>
</tr>
<tr>
<td>$\beta$</td>
<td>11.2</td>
<td>21.7</td>
<td>4.9</td>
<td>11.2</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>60.5</td>
<td>58.5</td>
<td>60.9</td>
<td>60.4</td>
<td>60.5</td>
<td>60.0</td>
</tr>
</tbody>
</table>
The orientation vector convention

orientation vector of the distal relative to the proximal frame

\[
\mathbf{n}_{cd} = \begin{bmatrix}
\gamma_{cdx} \\
\gamma_{cdy} \\
\gamma_{cdz}
\end{bmatrix}
\]

The problem is: in what system of reference should this vector be represented?
The options are:
• either the proximal or the distal frame
• the joint axes as defined by the Cardan convention

Do not forget: it is a totally abstract representation!


Sensitivity of the knee joint kinematics to the angular convention

1 - Cardan convention
2 - Orientation vector projection on the proximal axes
3 - Orientation vector projection on the Cardan (joint) axes
The position vector is represented relative to two points (rigid with the proximal and distal bone, respectively) and a set of axes of choice. The selected points may be the origins of the frames involved or two points arbitrarily identified.

Thus the three scalar quantities that represent position depend on the choice of the two reference points and the set of axes.
The axes with respect to which we represent the position vector:

An option is represented by the joint axes:

- **c** displacement along the distal z axis (coinciding with the proximal z axis)
- **a** displacement along the distal x axis (after the first rotation)
- **b** displacement along the distal y axis (after the second)

The points with respect to which we represent the position vector:

Example with reference to the knee joint:

- A point (P) in the proximal set of axes
- A point (D) in the distal set of axes

P and D coincide while the subject assumes an orthostatic posture.
The six degrees of freedom of a joint according to the Cardan convention

\[ \gamma \] about the distal z axis (coinciding with the proximal z axis)
\[ \alpha \] about the distal x axis (after the first rotation)
\[ \beta \] about the distal y axis (after the second rotation)
\[ c \] displacement along the distal z axis (coinciding with the proximal z axis)
\[ a \] displacement along the distal x axis (after the first rotation)
\[ b \] displacement along the distal y axis (after the second)

In summary

In order to determine the six quantities that describe the position and orientation of the distal bone relative to the proximal bone the following entities must be defined:

- A set of orthogonal axes rigid with the proximal bone (p)
- A set of orthogonal axes rigid with the distal bone (d)
- A point (P) in the proximal set of axes
- A point (D) in the distal set of axes
- The three axes with respect to which the position vector of the distal bone relative to the proximal bone is represented
- The axis about which the first rotation is performed
- The axis about which the second rotation is performed
- The axis about which the third rotation is performed
Knee joint kinematics vs orientation of the proximal axes

The representation of joint kinematics, whatever convention is chosen, is very sensitive to the definition of the set of axes involved:

- proximal frame rotated about the y axis of ±5°
- proximal frame rotated about the x axis of ±5°
- nominal reference systems

The two requirements are met by using anatomical frames.

These sets of axes are repeatable because they rely on identifiable anatomical landmarks.

They are anatomical axes and define anatomical planes: thus, the joint six degrees of freedom may be named in a manner consistent with functional anatomy.

The definition of anatomical frames is not unique. Possible definitions are …
**Pelvis**

*Conventional Gait Model* (Plug-in-Gait di VICON) \(^1\)
*Calibrated Anatomical System Technique (CAST)* \(^2\)
*ISB recommendation* \(^3\)


**Femur**

*Conventional Gait Model*
*CAST*
*ISB recommendation*

Femur

Conventional Gait Model
CAST
ISB recommendation

Mid-point between the femur epicondyles

Femur

Conventional Gait Model
CAST
ISB recommendation
JOINT KINETICS

The problem: musculo-skeletal loading...

Example: internal loads acting at the knee
Loads transmitted by relevant tissues

http://www.rad.upenn.edu/rundle/Knee/kneeMRICONT.html

Gastrocnemius, Medial Head
Gastrocnemius, Lateral Head

Patellar tendon
Loads transmitted by relevant tissues

- Semimembranosus Muscle
- Gastrocnemius, Medial Head
- Gastrocnemius, Lateral Head
- Patellar tendon

http://www.rad.upenn.edu/runderKnee/kneeMRICONT.html

 Loads transmitted by relevant tissues

- Bone-to-bone
- Semimembranosus Muscle
- Gastrocnemius, Medial Head
- Gastrocnemius, Lateral Head
- Patellar tendon

http://www.rad.upenn.edu/runderKnee/kneeMRICONT.html
Forces transmitted by muscles

distributed forces are assumed to be parallel and uniform

Q — centroid of the cross sectional area
Forces transmitted by muscles

- Gastrocnemius, Medial Head
- Gastrocnemius, Lateral Head
- Patellar tendon
- Semimembranosus Muscle

Forces exchanged between bones

- Gastrocnemius, Medial Head
- Gastrocnemius, Lateral Head
- Patellar tendon

http://www.rad.upenn.edu/runde/Knee/kneeMRICONT.html
Forces exchanged between bones: resultant force and couple

http://www.rad.upenn.edu/rundle/Knee/kneeMRICONT.html

Gastrocnemius, Medial Head
Gastrocnemius, Lateral Head
Patellar tendon
Semimembranosus Muscle
Bone-to-bone

http://www.rad.upenn.edu/rundle/Knee/kneeMRICONT.html
Forces exchanged between bones: resultant force

http://www.rad.upenn.edu/rundle/Knee/kneeMRICONT.html
Forces exchanged between bones: resultant force and couple

Internal load modelling
Muscles, tendons and ligaments are treated as if they were ropes!

- no 3-D modelling
- no interaction with surrounding muscles and bony structures is taken into consideration

Continuum mechanics (FEM) and a 3-D approach should be used.
The equations of motion (limited to plane motion)

\[
\begin{align*}
\mathbf{R} + \mathbf{W} + \mathbf{F}_h + \mathbf{F}_g + \mathbf{F}_p + \mathbf{F}_b &= m\ddot{\mathbf{a}}_{CM} \\
M^K_R + M^K_w + M^K_{F_h} + M^K_{F_g} + M^K_{F_p} + M^K_{F_b} + C_b + C_R &= I_K \alpha
\end{align*}
\]

Intersegmental force and couple: definition

for the time being the point K is chosen arbitrarily
Intersegmental force and couple: estimation

\[
\begin{align*}
\mathbf{R} + \mathbf{W} + \mathbf{F}_{\text{is}} &= \mathbf{m}\ddot{\mathbf{a}}_{\text{CM}} \\
\mathbf{M}_R^K + \mathbf{M}_W^K + \mathbf{M}_{\text{Fs}}^K + \mathbf{C}_{\text{is}} + \mathbf{C}_R &= I_K \alpha
\end{align*}
\]

kinematic quantities

inertia parameters

reaction forces

Kinematic quantities

For each body segment of interest, the following quantities are estimated:

- position vector and orientation matrix, relative to the laboratory (g) frame, of the anatomical frame (a), in each sampled instant of time

  \[ g\mathbf{t}_a, g\mathbf{R}_a \]

- local position vector of the intersegmental loads reduction point K

  \[ a\mathbf{p}_K \]
Kinematic quantities & inertia parameters

For each body segment of interest, the following quantities are estimated:

- Position vector and orientation matrix, relative to the laboratory (g) frame, of the anatomical frame (a), in each sampled instant of time
- Local position vector of the intersegmental loads reduction point K
- Mass
- Local position vector of the CM
- Principal axes of inertia (i) orientation matrix relative to the anatomical frame (a)
- Moments of inertia

Intersegmental force and couple: estimate

\[ \overline{R} + \overline{W} + \overline{F}_{is} = m\overline{a}_{CM} \]
\[ M_R^K + M_W^K + M_{F_{is}}^K + C_{is} + C_R = I_k\alpha \]
Forces exchanged between foot and floor

(ground reactions)
Foot-ground contact area during level walking

Forces acting on the force plate

in a given instant of time

distributed forces

force-couple system
The force plate supplies six scalar quantities

For each body segment interacting with the environment, the following quantities are estimated:

• three force components
• three couple components.

These quantities are given with respect to the dynamometer frame. Since, normally, the kinematic quantities are given with respect to another set of axes (referred to as the laboratory axes), the transformation matrix between the former and the latter set is to be provided.
Intersegmental force and couple: estimate

\[ \begin{align*}
R + \bar{W} + \bar{F}_{is} &= m\bar{a}_CM \\
M^K_R + M^K_W + M^K_{Fis} + C_{is} + C_R &= I_K \alpha
\end{align*} \]

inverse dynamics

\[ \begin{bmatrix} F_{is} \\ C_{is} \end{bmatrix} \]

How accurately do we estimate the intersegmental force and couple?
Do intersegmental loads carry functional information?

Intersegmental force and couple: accuracy factors

- The physical model (degrees of freedom)
- Inertia parameter estimate
- Time differentiation
- External forces
- Position and orientation reconstruction of the model links
- External and internal anatomical landmarks identification
Intersegmental force and couple: accuracy

Model (includes input data errors) fidelity assessment

*Herbert Hatze, Journal of Biomechanics, 2002*

- open kinematic chain
- 2-D model
- 3 dof

---

Intersegmental force and couple: accuracy

*estimated using photogrammetric data (inverse dynamics)*
*measured*

- A-P FORCE (N)
- VERTICAL FORCE (N)
- M-L COUPLE (Nm)

*average rms difference = 17% of peak-to-peak value*
*average correlation coefficient = 0.87*
Redundancy may be exploited for fine tuning the parameters and variables involved.

In the bottom-up approach a possible criterium is to minimize the trunk residual moment and force.

Intersegmental force and couple: accuracy

Position and orientation reconstruction of the model links
- photogrammetric errors
- soft tissue artefacts
- anatomical landmark identification
Shank soft tissue artefacts: effect on knee intersegmental couple

Intersegmental couple [Nm]

- Flexion/extension
- Adduction/abduction
- Internal/external rot.

% of stance

Manal et al., *Gait and Posture*, 2002

---

Problems still seeking for an optimal solution

- minimization of skin movement artefacts and/or their assessment and compensation
- minimization of misidentification of both internal and external anatomical landmarks
- identification of the bone-to-bone resultant force application line
- standardization of procedures
- muscle, tendon, and ligament modelling
Do intersegmental loads carry functional information?

\[ \mathbf{R} + \mathbf{W} + \mathbf{F}_{is} = m \ddot{\mathbf{a}}_{CM} \]

\[ M_{R}^{K} + M_{W}^{K} + M_{F_{is}}^{K} + C_{is} + C_{R} = l_{K} \alpha \]

all vectors are represented in the global (inertial frame)

The intersegmental couple

\[ \overline{C}_{is} = \overline{M}_{F_{h}}^{K} + \overline{M}_{F_{g}}^{K} + \overline{M}_{F_{p}}^{K} + \overline{M}_{F_{b}}^{K} + \overline{C}_{b} \]

point K was chosen arbitrarily!
Forces exchanged between bones: resultant force and couple

In this case we may refer to the intersegmental couple as muscular moment.
The challenge

is to find the point Q for which it is true that

$$\bar{M}_b^Q + \bar{c}_b = 0$$

and thus:

$$\bar{c}_{is} = \bar{M}_{F_h}^Q + \bar{M}_{F_g}^Q + \bar{M}_{F_p}^Q$$

If the knee joint is modelled using a spherical hinge

by definition

$$\bar{c}_b = 0 \quad \bar{M}_b^Q = 0$$

and, thus, the intersegmental couple is the muscular moment
The muscular forces

\[
\overrightarrow{C}_{is} = \overrightarrow{M}_{Fh} + \overrightarrow{M}_{Fg} + \overrightarrow{M}_{Fr}
\]

This relationship cannot be solved with respect to a single muscular force unless it is known or assumed that only one muscular force is present.

Gait Analysis
**Gait Phases**

The body center of mass rotates around the support and increases its potential energy during the initial stance phase. This energy is converted in kinetic form during the second stance phase (Cavagna et al. 1977). If center of mass is accelerated forward.

**Inverse Pendulum**

The body center of mass rotates around the support and increases its potential energy during the initial stance phase. This energy is converted in kinetic form during the second stance phase (Cavagna et al. 1977). If center of mass is accelerated forward.
Joint Moments during Normal Gait

<table>
<thead>
<tr>
<th>Joint</th>
<th>Nm/kg</th>
<th>0</th>
<th>-1.0</th>
<th>1.0</th>
<th>-1.0</th>
<th>0.5</th>
<th>-0.75</th>
<th>-2.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexor (+)</td>
<td>1.0</td>
<td>0</td>
<td>-1.0</td>
<td>1.0</td>
<td>-1.0</td>
<td>0.5</td>
<td>-0.75</td>
<td>-2.00</td>
</tr>
<tr>
<td>Knee Extensor (+)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle Dorsiflexor (+)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% stance

Joint Moment Interpretation

Limitations

• Cannot distribute moment among each agonist of a muscle group
• Moment does not account for co-contraction (moment = agonist + antagonist effects)
• Moment reflects contributions from active (muscular) and passive (ligament, joint contact) sources
• Areas of caution
  • End range of motion
  • External devices – orthoses, prostheses
Electromyography

Electromyography (EMG) – Study of muscle function through the examination of the muscle’s electric signals

Why EMG?
- Estimate *in vivo* muscle forces for various activities
- Help solving the inverse dynamic problem
- Detect muscle fatigue
- Quantify pathological muscle behaviour
History

• Luigi Galvani – 1791
  – Observed the relationship between muscle and electricity by depolarizing frog legs with metal rods
  – Father of neurophysiology
  – *De Viribus Electricitatis* – work was introduced
• Carlo Matteucci – 1838
  – Proved that electric currents originated in muscles
• Du Bois-Reymond – 1849
  – Designed a Galvanometer to record electrical current
  – Reduced skin impedance by rubbing blisters on his arms and opening them

Galvani

Figure 3.2. Galvani’s demonstrations of the effects of electricity on muscles of frogs and sheep. (From Fulton’s reproduction of a plate in Galvani’s *De Viribus Electricitatis in Motu Musculari* Commentarius, 1792.)

De Luca 1985
EMG types

• Surface EMG (SEMG) – Electrodes are applied to the surface of the skin.
  – Used to measure muscle signals in large muscles that lie close to the surface of the skin
• Indwelling EMG – Electrodes are inserted into the muscle (usually via a needle)
  – Used to measure muscle signals in small or deep muscles, which cannot be adequately monitored using SEMG.

EMG Characteristics

• Ranges from 0-10mV (peak to peak)
• Usable frequency range: 0-500Hz
  – Dominant frequencies 50-150Hz
• Random in nature
  – Mixture of signals from different motor units
**Action Potentials**

De Luca 1982

**Surface or Indwelling EMG Electrodes**

- **Single electrode with reference**
  - Measure action potential at one electrode
  - Subtract common as measured from reference

- **Two electrodes with reference**
  - Measure action potentials at both electrodes
  - Use differential amplifier
  - Subtract common signal at source
  - Amplify differences
Noise

• EMG signals are very small
• External noise
  – Electronics noise
    • Recording/measuring equipment
  – Ambient noise
    • TV, radio, overhead lights
  – Motion artifact
    • Movement of electrodes or wires

Electrode Placement

• Place electrodes
  – In line with muscle fibers
  – At the midline of the muscle
• Not over or near tendon insertion sites or innervation zone (motor point)
  – Electrical stimulation at this point results in muscle contraction
  – Action potentials move oddly and EMG detection is affected
• Reference electrode is far away and over electrically neutral area
Electrode Placement

Effects of Muscle Fatigue on EMG Signal

De Luca
Experimental Example

Agonist and Antagonist Muscle Activity

De Luca 1985
Data Acquisition and Analysis

- Sampling
  - 1024 Hz, 12 bit resolution
  - Bandpass 1st order filter: 10-500Hz
- Filter Data
  - Full wave rectified
  - 4th order Butterworth filter: Fc = 3Hz (smooth)
  - Further analysis options
    - Integrated over specific time periods for iEMG

EMG Limitations

- Difficult to compare between subjects
- SEMG is not appropriate for all muscles
- Electrode positioning must be consistent
- MVC can vary between days and time of day
- Can’t ensure that all motor units are firing for MVC
- Difficult to hold isometric contractions for some muscles
- Force is not proportional to EMG amplitude for many muscles
- MUST CALIBRATE AT START OF SESSION
SUMMER SCHOOL 2006 – Monte S.Pietro, Bologna

ADVANCED TECHNOLOGIES FOR NEURO-MOTOR ASSESSMENT AND REHABILITATION

Thank you