Successful Practices for Instrumented Gait Analysis: Insight from CMLA Accreditation
- Dynamic EMG -

2017 GCMAS Annual Conference – Tutorial #3
Salt Lake City, UT – May 23, 2017

James Carollo, Ph.D., P.E.
Director, Center for Gait and Movement Analysis (CGMA)
Director, Musculoskeletal Research Center (MRC)
Children’s Hospital Colorado
Associate Professor, Departments of PM&R, Orthopedics, Bioengineering
University of Colorado, Anschutz Medical Campus

Conflict of Interest

James Carollo has no conflict of interest with any commercial venture described in this presentation.
Learning Objectives

Describe successful practices for dynamic electromyography (D-EMG) in a clinical environment that promote accuracy and reliability of recordings

- Understand existing methods and standards
- Employ practical techniques for maximizing signal quality

Introduce useful quality assurance procedures

- During instrumented gait analysis
- Periodic quality assurance testing

Strategies to communicate these practices on a CMLA Accreditation application

Dynamic Electromyography

- Measures muscle activation pattern during a dynamic (functional) activity
- Uses electrodes, amplifiers and computers to record pattern
- Greater amplitude corresponds to more muscle activity
Generation of the EMG Signal

Schematic of Motor Unit Innervation and Motor Unit Action Potential (MUAP)
Monopolar vs. Bipolar Configuration

- **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 (CMRR)
  - Amplify difference between electrodes only

Bipolar Surface EMG Recording of MUAP

- Magnitude of MUAP at either electrode is inversely proportional to $d$

Changing wave of depolarization along muscle fiber membrane
Bipolar Surface EMG Recording of MUAP

- Bipolar wave at recording electrodes produced as repolarization passes under electrode site
- Since signal amplitude is attenuated by the square of distance “d”, excess subcutaneous tissue will significantly reduce signal magnitude

Summation of Motor Unit Action Potential (MUAP)

Signal Characteristics of Surface EMG

- EMG p-p Amplitude: 10 mV (-5 mV to +5 mV) prior to amplification*
- Useable frequency range: 0 - 500 Hz
- Dominant frequency range: 50 – 150 Hz
- Random in nature
  - Interference pattern derived from signals (MUAP) from different motor units

* In practice; EMG amplitude < 1mV pp

Early Studies Support Correlation Between EMG Amplitude and Muscle Force Production

Components of ALL D-EMG Systems

- While the sequence may change by vendor or transmission type (analog or digital, wired or wireless), ALL D-EMG systems must include all of these stages
- Each has options that need to be matched to the application
- Each option impacts the quality of the recorded EMG signal
- While complex, help is available in the form of standards

<table>
<thead>
<tr>
<th>Electrodes</th>
<th>Pre-amp / BP Filter</th>
<th>Transmission - wired/wireless</th>
<th>Base Station Gain Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMG Processing</td>
<td>Sampling–A/D Conversion</td>
<td>High-pass Filter (Motion Artifact)</td>
<td>Low-pass Filter (Aliasing)</td>
</tr>
</tbody>
</table>

SENIAM Project: Surface Electromyography for the Non-Invasive Assessment of Muscles

- European-concerted (i.e. government sponsored) action in the Biomedical Health and Research Program of the EU
- Objectives of the SENIAM project:
  - Solve key items that prevent useful exchange of data
  - Integrate basic and applied research on surface EMG at the EU level in order to establish European co-operation
- The SENIAM project has resulted in:
  - Recommendations for sensors, sensor placement, signal processing
  - a set of simulation models for education and testing
  - a set of test signals
  - eight books and numerous other publications
  - European network for Surface EMG: the SENIAM club.

www.seniam.org
The SENIAM Project: Deliverables

- A detailed description of the main sensor (electrodes and pre-amp) characteristics
- A clear description of muscle anatomy to facilitate correct sensor placement
- Sensor location and orientation for selected muscles
- Clinical tests to evaluate the sensor placement procedure
- S-EMG recording: sampling, signal conditioning and filtering, A/D conversion
- Procedures for amplitude normalization during dynamic and non-dynamic contractions, including MVC

Selected SENIAM Recommendations for IGA

**Electrodes / Sensor**

- Configuration: only bipolar configuration
- Size of active area: no larger than than 1 cm in the direction of the muscle fibers
- Orientation: bipolar pair aligned in the direction of the long axis of muscle
- Inter-electrode distance: 2 cm, or no greater than ⅓ of the muscle length
- Material: pre-gelled, disposable Ag/AgCl
- If using “dry-type” electrodes, amplifier input impedance must be > 100K Mohms
Selected SENIAM Recommendations for IGA

Skin prep for good electrode/skin contact:
- Shave hair if it is covering electrode site
- Clean with alcohol and let dry completely
- Impedance: Ideal < 5Kohms, OK < 30Kohms
- Locations muscle specific, but in general ½ distance between most distal motor end plate and tendon insertion

EMG recording and processing
- Filtering: 10 Hz – 350 Hz
- Sampling: minimum 1KHz
- A/D conversion: 16 bit

Tips for Using SENIAM Recommendations
- Consider SENIAM as a starting point
- Confirm your EMG system complies with these recommendations
- Confirm they produce the expected results
  - Low noise, skin impedance and crosstalk
  - Accurate and repeatable EMG signals
- If they work sufficiently for your application, document that you follow them in Parts I, II, and III of the CMLA application
What about small or deep muscles?

- **Surface EMG (SEMG)** – Electrodes are applied to the surface of the skin.
  - Generally most appropriate to measure muscle activations in large muscles that lie directly under the skin surface
- **Indwelling EMG** – Electrodes are inserted into the muscle (needle, or fine wire)
  - Used to measure muscle signals in small or deep muscles, which cannot be adequately monitored using surface EMG.
**EMG Filtering: Band Pass**

![EMG Spectral Density Graph](http://www.isek-online.org/standards_emg.html)

**Freeborn, Antonelli, Perry, 1979**

- Since the power spectral density plot for EMG shows little frequency content outside the range of 5-500 Hz, **surface** EMG should typically be filtered between 10-350 Hz (SENIAM, ISEK).
- Intramuscular signals should be filtered in the 10-450 Hz range.

---

**Surface Electrodes**

**Advantages**

- Quick, easy to apply; easy to reposition
- No medical supervision (does require training)
- Represents larger volume of MUAP, overall muscle activity

**Disadvantages**

- Only appropriate for measuring superficial muscles
- Often requires skin abrasion to reduce skin impedance

- **Crossstalk from adjacent muscles**
  - Sometimes alters movement patterns of the subject when tape or compression wrap holding electrodes is excessive
Crosstalk in Surface EMG

- Crosstalk derived from adjacent muscles “contaminating” the intended muscle’s signal from their own MUAP
- Take extra care when recording surface EMG from small muscles and areas with significant subcutaneous fat, as it is known that adipose tissue enhances crosstalk.

**Best Remedy:**
- Standardize electrode diameter and inter-electrode distance across subjects and between recording sessions
- Recognize EMG placements susceptible to crosstalk
- Consider using fine-wire electrodes

Indwelling Electrodes (fine wire)

**Advantages**
- Extremely sensitive
- Record the activity of a small number of motor units
- Access to deep musculature
- Minimal crosstalk from other muscles

**Disadvantages**
- Extremely sensitive
- Requires medical personnel, certification
- Little opportunity to reposition once inserted
- Often affects movement pattern of the subject
- Detection area may not be representative of entire muscle
2 Simple Practices that Can Improve EMG Quality at Every Analysis

1. Find the **optimal** sensor/electrode location for each patient
2. Use a live pre-test recording to recognize and eliminate **noise** in your dynamic EMG signal

Optimal Electrode Placement #1

- **Start from a trusted standard protocol**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus</td>
<td><strong>1/2</strong> midpoint from anterior aspect of ilium between anterior superior iliac spine and inguinal border of patella (lower cap). Flex knee while subject is sitting and have them lift thigh up, recruiting a pushing on the lower thigh. Find the belly of the muscle. If you feel proximal, get superior signal. If you feel distal, get inferior signal.</td>
</tr>
<tr>
<td>Femoris</td>
<td><strong>1/3</strong> midway from anterior aspect of ilium between anterior superior iliac spine and inguinal border of patella (lower cap). Flex knee while subject is sitting and have them lift thigh up, recruiting a pushing on the lower thigh. Find the belly of the muscle. If you feel proximal, get superior signal. If you feel distal, get inferior signal.</td>
</tr>
<tr>
<td>Vastus Lateralis</td>
<td><strong>4/5</strong> of the distance from the greater trochanter to the antero-lateral patellar (knee cap) surface—palpating muscle to confirm, and find muscle belly by extending knee. Electrode plane in line of rectus fiber.</td>
</tr>
<tr>
<td>Medial Hamstring</td>
<td>Palpate tendons (proximal medial margins of popliteal fossa). Place electrodes 1/3 distance along line connecting tendon and ischial tuberosity.</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td><strong>1/3</strong> of distance between tibial tuberosity and lateral malleolus. Palpate the tibial crest and place electrode immediately slightly lateral to tibial crest.</td>
</tr>
<tr>
<td>Peroneal (Peronaeus Brevis)</td>
<td>Within <strong>1/3</strong> of distance from tip of lateral malleolus to tibial crest head. Palpate tendon above lateral malleolus (find just posterior to lateral malleolus) and move up proximally to find muscle belly. Avoid creases area.</td>
</tr>
<tr>
<td>Medial Gastrocnemius</td>
<td><strong>1/3</strong> distance from ankle joint point forward at popliteal fossa border (between heads of gastrocnemius) and move medially and place electrodes over belly of muscle <strong>1/3</strong> distance down.</td>
</tr>
</tbody>
</table>

**Optimal Electrode Placement #2**

- Consider your **patient’s specific anatomy** and confirm your standard protocol is still consistent with the core placement guidelines
  - Align the bipolar pair along the long axis of the muscle parallel with the muscle fibers
  - Stay close to the midline of the muscle belly
  - Choose a location midway between the most distal motor point and the tendinous insertion

---

**Optimal Electrode Placement #3**

- **Avoid** a placement that is too close to adjacent muscles
- **Avoid** placing directly over the tendon insertion sites or innervation zone (motor point)

---

Carlo De Luca (1997)
Sources of Noise in EMG Signal

- **Physiologic Noise**: ECG, respiratory signals, etc.
  - Reduced by proper positioning of the electrode (location & orientation), filtering
- **Ambient Noise**: Power line radiation (60 Hz), overhead lights, TV, radio
  - Removed by differential amplifiers, shielding
- **Baseline Noise**: Electro-chemical noise (skin-electrode interference)
  - Reduced by effective skin preparation
- **Movement Artifact Noise**: Movement of electrode with respect to the skin, movement of the wires
  - Reduced by effective skin preparation, proper fixation of the electrode to the skin, filtering

**Relationship of Skin Impedance and Noise**

- **Direct** relationship between measured impedance at skin-electrode junction and the noise magnitude
  - Huigen 2002; Stegeman and Hermens 2001, SENIAM

- **Indirect** relationship between amount of skin abrasion and both noise and impedance measured
  - Huigen 2002
EMG Confirmation Trial

Where to Report EMG Practices in CMLA Accreditation Application

• Part I: Administration & Personnel
  • Question 3: Components of a clinical exam
    • CR 11: Measures and reports EMG
    • CR 12: Simultaneous capture of kinematics, kinetics and EMG
  • Question 5: Laboratory procedures
    • CR 23: Procedure manual for S-EMG electrode placement
    • CR 24: Procedure manual for I-EMG electrode placement
Where to Report EMG Practices in CMLA Accreditation Application

**Part I: Administration & Personnel (continued)**

- **Question 6: Competency (surface / fine-wire)**
  - CR 29: Initial competency
  - CR 30: Maintaining competency
- **Question 7: Quality assurance (surface / fine-wire)**
  - CR 31: Describe quality assurance program
  - CR 32: Consistency within personnel
  - CR 33: Consistency between personnel

---

Where to Report EMG Practices in CMLA Accreditation Application

**Part II: Equipment & Data Collection**

- **Question 2: Hardware**
  - CR 38: Equipment table, EMG
  - CR 41: Capability to measure dynamic EMG
  - CR 42: Evidence of synchronization hardware
- **Question 4: Calibration, accuracy, repeatability**
  - CR 49: Calibration of EMG system
  - CR 50: Evidence vendor’s calibration procedures are followed
  - CR 51: Accuracy (validity) of EMG system
  - CR 52: Precision (repeatability) of EMG system
Where to Report EMG Practices in CMLA Accreditation Application

• Part III: Data Processing / Management / Reporting
  • Question 1: Software for data processing
    • CR 59: Description of EMG data reduction software
    • CR 63: Strengths and weaknesses of EMG software
  • Question 2:
    • CR 65: Control EMG description (subjects, processing)
    • CR 68: Details of control data set if taken from literature
    • CR 70: Compiled reference data from control data set
  • Question 4: Example clinical report
    • CR 75: EMG reporting format

Take Home Message

• Understanding the fundamental principles of EMG generation and recording can lead to improved quality and better interpretation
• Utilize existing standards as a way to establish core practices in your laboratory
• Surface and fine-wire electrodes can both be successful approaches to recording EMG
• Consider including the 2 simple practices to improve the quality of your EMG results
Acknowledgement

Special Thanks to my colleagues who helped provide valuable insight in the preparation of this seminar

- Eddie Cramp, Motion Lab Systems
- Marilyn Wyatt, Naval Medical Center San Diego
- SENIAM Project