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

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Conflict of Interest

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

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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

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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

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Generation of the EMG Signal

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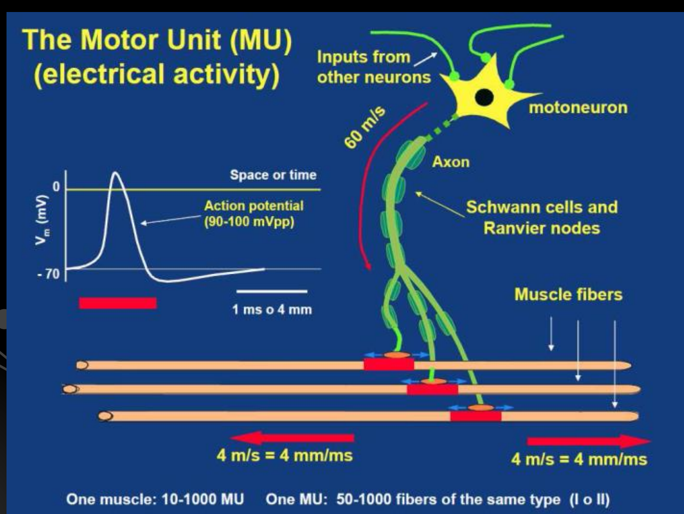
Schematic of Motor Unit Innervation and Motor Unit Action Potential (MUAP)



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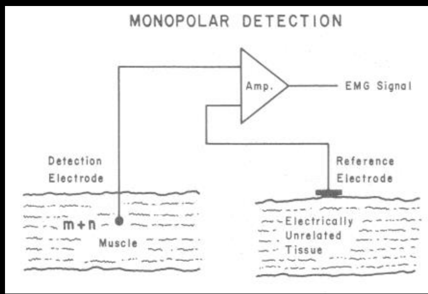
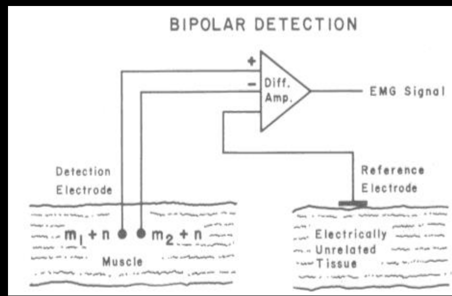
Monopolar vs. Bipolar Configuration





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

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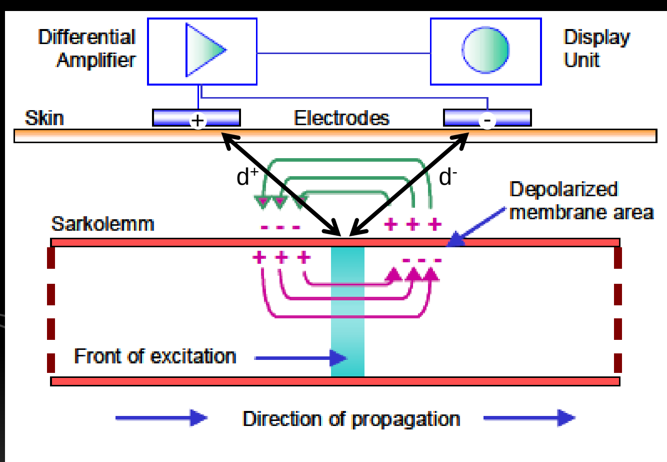
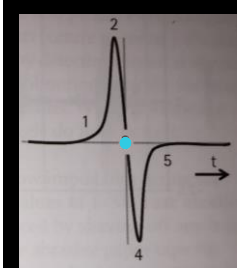
Bipolar Surface EMG Recording of MUAP



Magnitude of MUAP at either electrode is inversely proportional to *d*



Changing wave of *depolarization* along muscle fiber membrane

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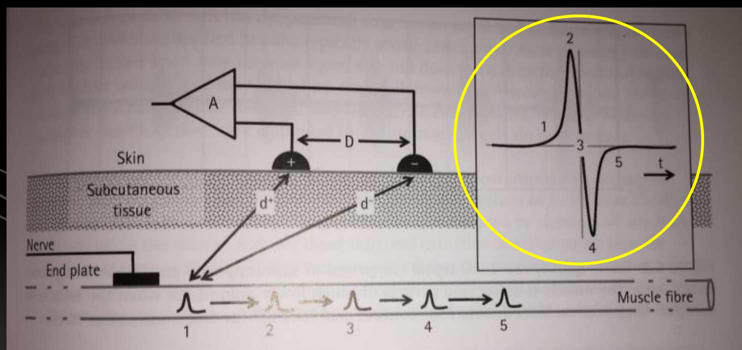
Bipolar Surface EMG Recording of MUAP

- 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



Baker R: Measuring Walking – *A Handbook of Clinical Gait Analysis*, Mac Keith Press, 2013.

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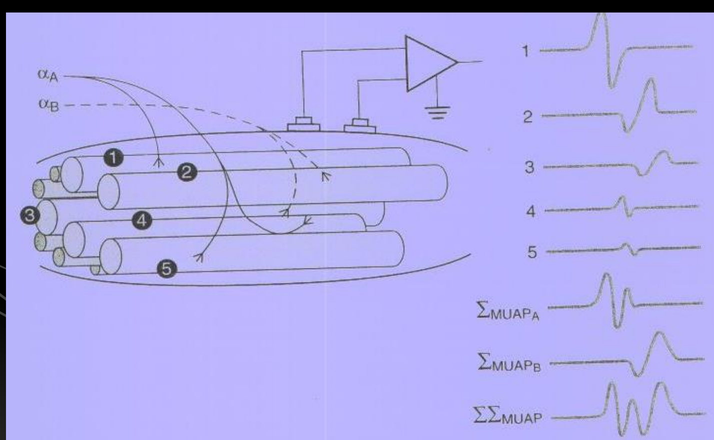
Summation of Motor Unit Action Potential (MUAP)



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Signal Characteristics of Surface EMG

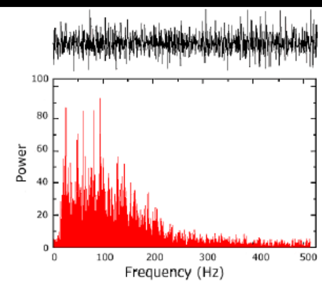

Figure 1: Frequency spectrum of the EMG signal detected from the Tibialis Anterior muscle during a constant force isometric contraction at 50% of voluntary maximum.

- EMG p-p Amplitude: 10 mV (-5mV 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

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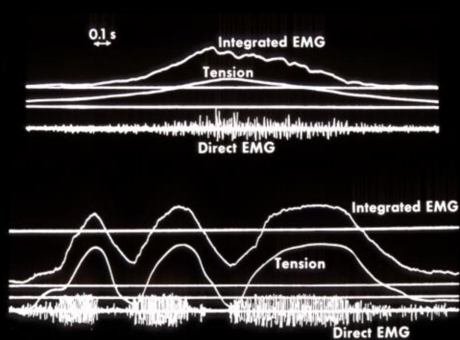
Early Studies Support Correlation Between EMG Amplitude and Muscle Force Production

From Ralston et al.: Am. J. Physiology, 151:612, 1947.



From Inman et al.: Electroenceph. Clin. Neuro-physiology, 4:187, 1952.

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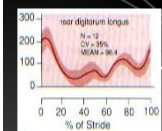
Components of *ALL* D-EMG Systems

- 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



Electrodes → Pre-amp / BP Filter → Transmission - wired/wireless → Base Station Gain Stage → Low-pass Filter (Aliasing) → High-pass Filter (Motion Artifact) → Sampling–A/D Conversion → EMG Processing

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SENIAM Project: *<u>S</u>urface <u>E</u>lectromyography for the <u>N</u>on-<u>I</u>nvasive <u>A</u>ssessment of <u>M</u>uscles*

- 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

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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

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Selected *SENIAM* Recommendations for IGA

Electrodes / Sensor

- Configuration: only bipolar configuration
- Size of active area: no larger than than 1cm 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 ¼ of the muscle length
- Material: pre-gelled, disposable Ag/AgCl
- If using "dry-type" electrodes, amplifier input impedance must be > 100K Mohms

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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

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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

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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.

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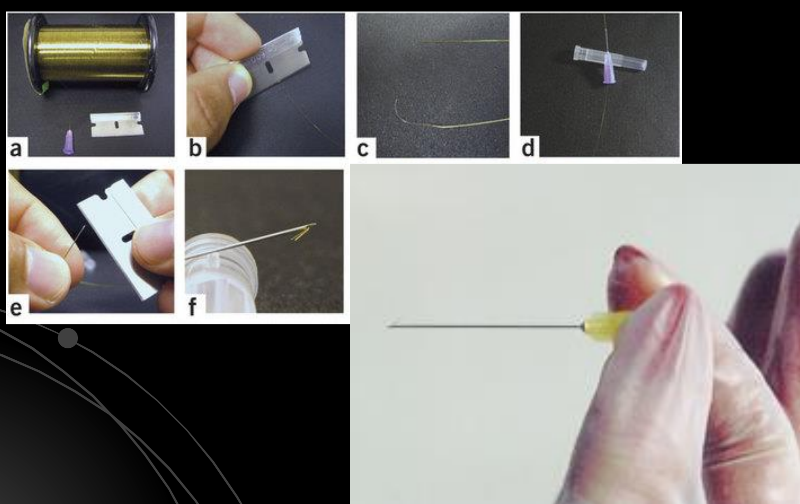
Indwelling Electrode (Fine Wire)



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EMG Filtering: Band Pass

10.2 RECORDING OF THE ELECTROMYOGRAM 261

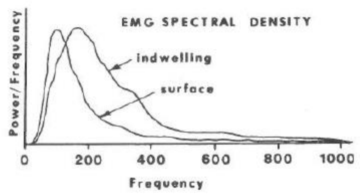

Figure 10.7 Frequency spectrum of EMG as recorded via surface and indwelling electrodes. The higher-frequency content of indwelling electodes is the result of the closer spacing between electrodes and their closer proximity to the active muscle fibers.

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.

http://www.isek-online.org/standards_emg.html

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

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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

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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

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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

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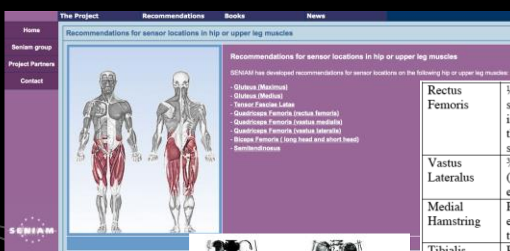
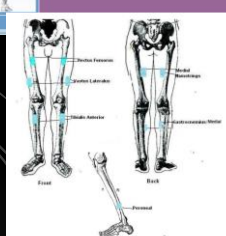
Optimal Electrode Placement #1

- Start from a **trusted standard protocol**





Rectus Femoris	½(Midway) from anterior aspect of thigh between anterior superior iliac spine and superior border of patella (knee cap). Flex knee while subject is sitting and have them lift thigh up, resisting a pushing on the lower thigh. Find the belly of the muscle. If put too proximal, get sartorius signal. If put too distal, may get vasti signal.
Vastus Lateralus	¾ 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. Electrodes place in line of muscle fiber.
Medial Hamstring	Palpate tendon (proximal medial margin of popliteal fossa). Place electrodes 1/3 distance along line connecting tendon and ischial tuberosity.
Tibialis Anterior	Proximal 1/3 of distance between tibial tuberosity and lateral malleolus. Palpate the tibial crest and place electrodes immediately/slightly lateral to tibial crest.
Peroneal (Peroneus brevis)	Within ¼ to 1/3 of distance up from tip of lateral malleolus to fibular head. Palpate tendon above lateral malleolus (feel just posterior to lateral malleolus) and move up proximally to find muscle belly. Avoid triceps surae.
Medial Gastroc	¼ distance from midway point found at popliteal fossa border (between heads of gastrocs) and move medially and place electrodes over belly of muscle ¼ distance down.

Perotto (1994), Cahill et al (1995)

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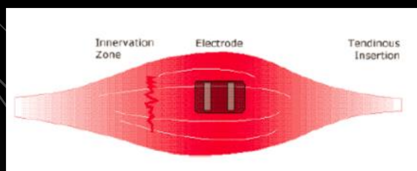
Optimal Electrode Placement #2

- 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



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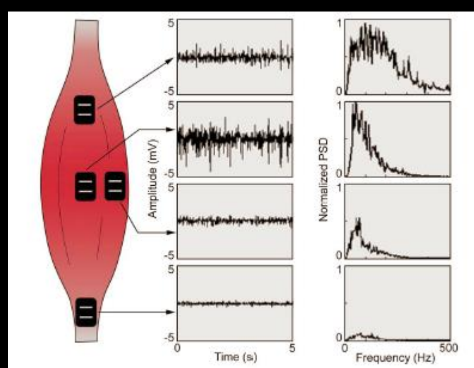
Optimal Electrode Placement #3

- 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)

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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

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Relationship of Skin Impedance and Noise

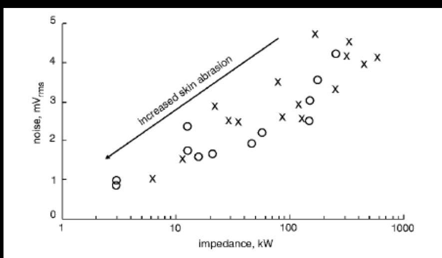

Fig. 9 *Noise (RMS, 0.5–500 Hz) as function of impedance (DC) of Ag–AgCl wet-gel electrodes. (×) 15 different test subjects; (○) one subject, with different degrees of skin abrasion*

Huigen et al. 2002

- 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

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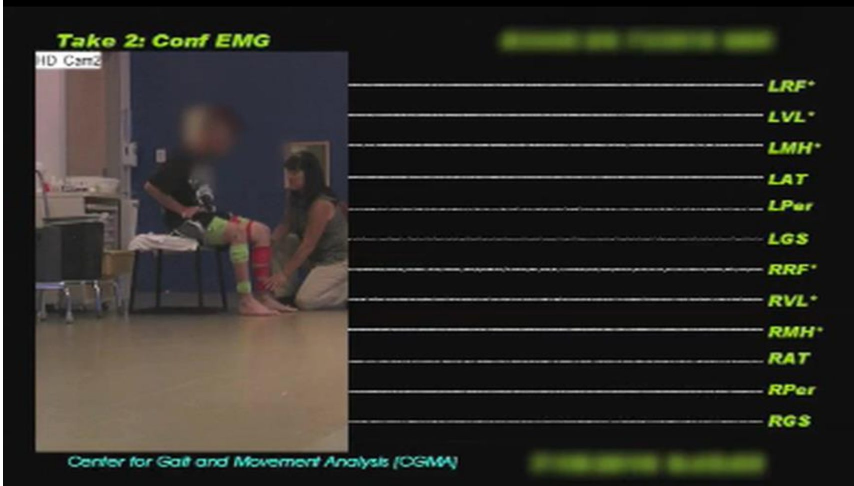
EMG Confirmation Trial



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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

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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

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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

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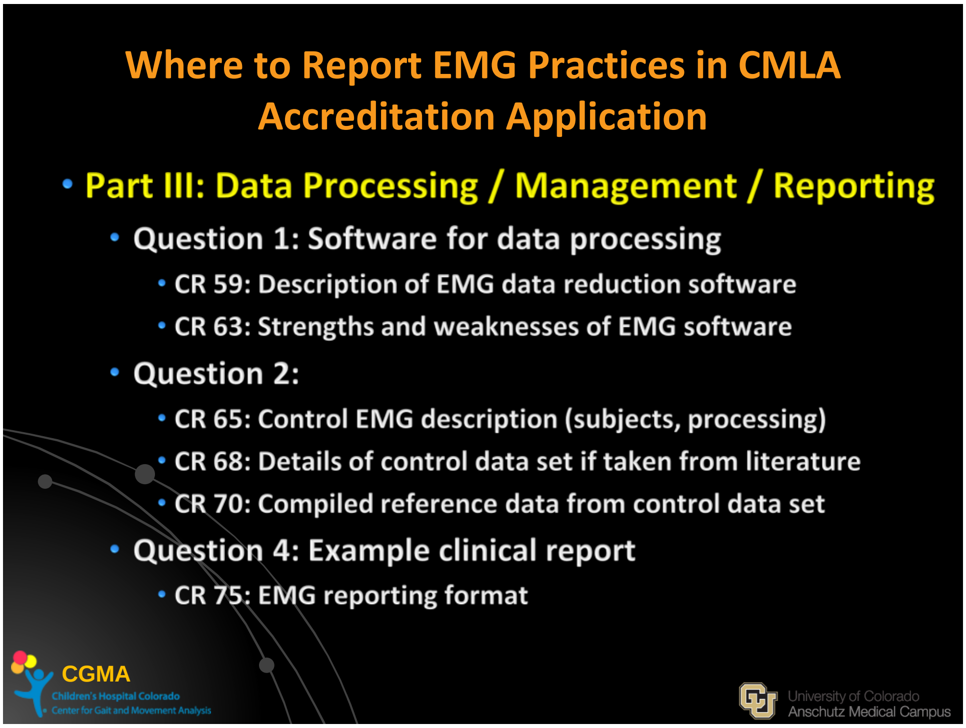
Where to Report EMG Practices in CMLA Accreditation Application
Part III: Data Processing / Management / Reporting
Question 1: Software for data processing
CR 59: Description of EMG data reduction software
CR 63: Strengths and weaknesses of EMG software
Question 2:
CR 65: Control EMG description (subjects, 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
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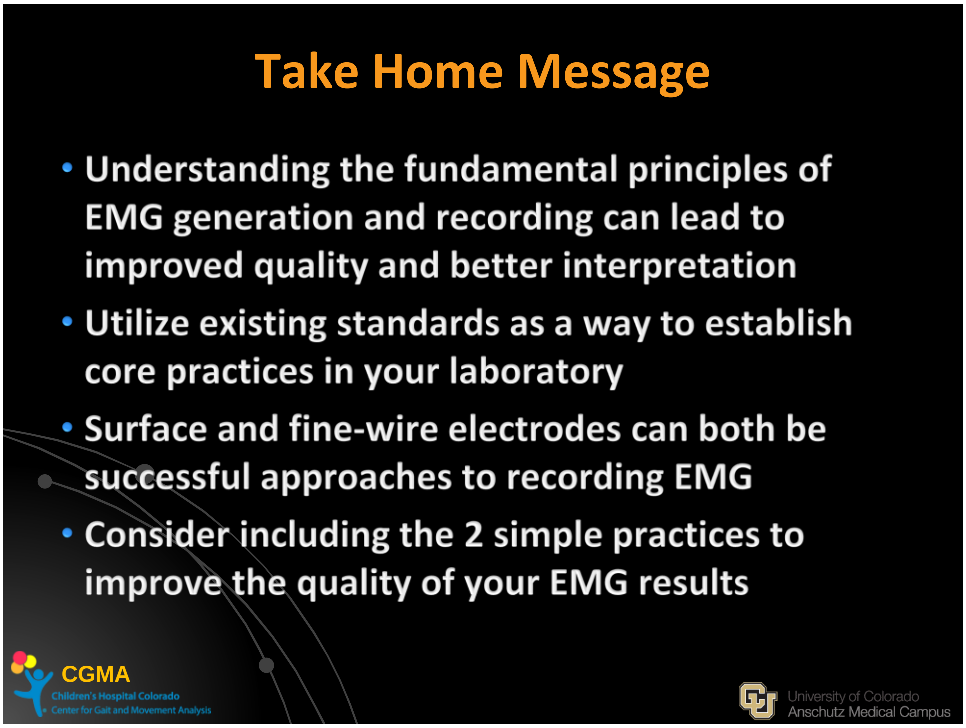
Take Home Message
Understanding the fundamental principles of EMG generation and recording can lead to improved quality and better interpretation
Utilize existing standards as a way to establish core practices in your laboratory
Surface and fine-wire electrodes can both be successful approaches to recording EMG
Consider including the 2 simple practices to improve the quality of your EMG results
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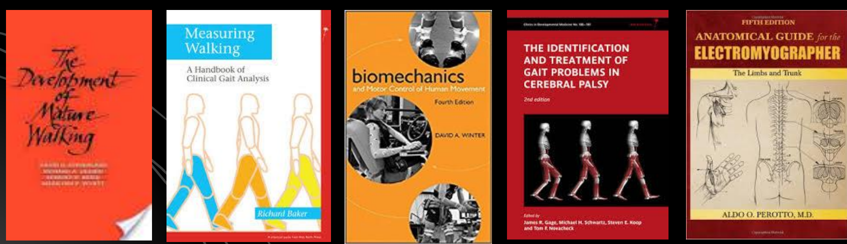
Acknowledgement

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



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