The Musculature

ODS 514
Anatomy and Physiology of the Masticatory System

Reading: Mohl, et al., Chapter 7

W.D. McCall, Jr., Ph.D.

Topics to be Covered

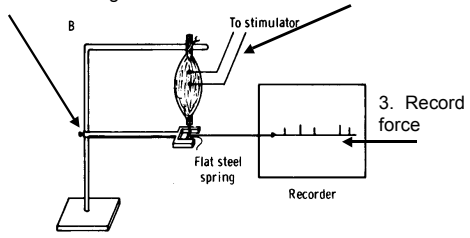
I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Some trigeminal reflexes
V. Selected dental controversies

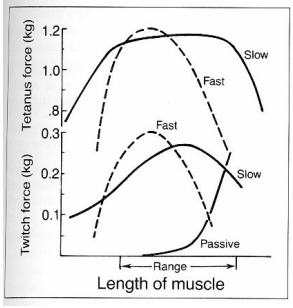
I. Properties of Muscle

A. Common with limb muscle
   1. Length-tension curve
   2. Force-velocity curve
   3. Determinants of muscle force
B. Peculiar to jaw muscles
   1. Anatomy of origins and insertions
   2. Location of some sensory cell bodies
   3. Organization of some reflexes

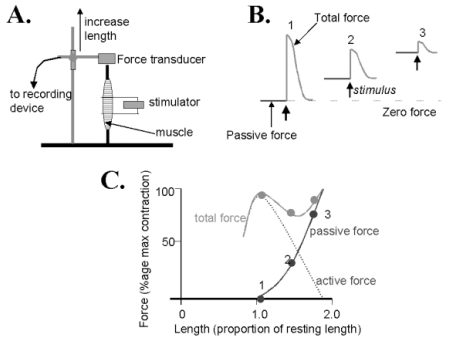
The Length-Tension Experiment

1. Set muscle length
2. Stimulate nerve to muscle



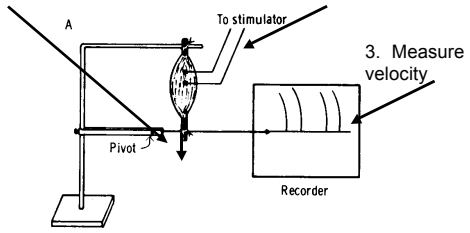


Features:
1. Tetanic force > twitch force
2. Fast & slow fibers differ
3. Part of force is passive



The Force-Velocity Experiment

1. Set weight to lift
2. Stimulate muscle
3. Measure velocity



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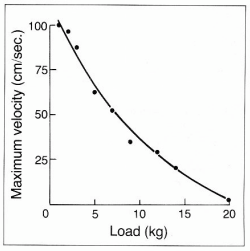

Feature:
Faster is weaker

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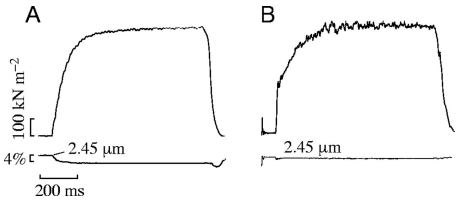
Example records of fused isometric tetanus of an isolated muscle fiber of mouse



Edman, K. A. P. J Exp Biol 2005;208:1905-1913

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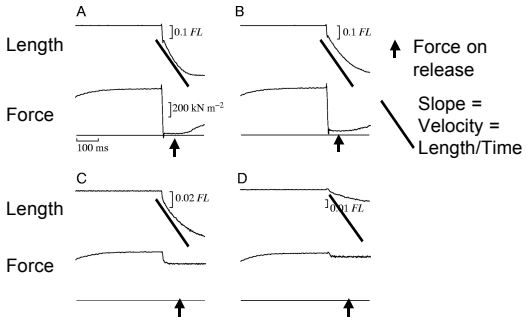
Load-clamp recordings at four different force levels during tetanus



Edman, K. A. P. J Exp Biol 2005;208:1905-1913

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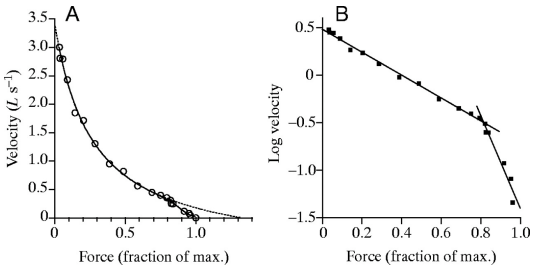
Biphasic force-velocity relationship



Edman, K. A. P. J Exp Biol 2005;208:1905-1913

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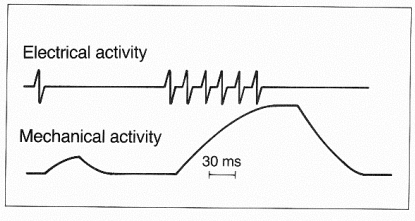

Features:
1. Delay from action potential to twitch
2. More force from a shower of action potentials

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Determinants of Muscle Force

1. Length
2. Velocity
3. Delay from electrical to mechanical events
4. Number of motor units recruited
5. Frequency of stimulation
6. Anatomy of origin and insertion

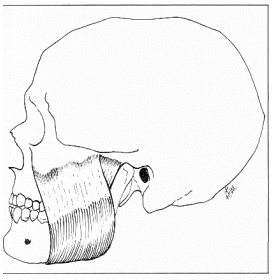
Topics to be Covered

I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Some trigeminal reflexes
V. Selected dental controversies

II. Muscles of mandibular function

A. Jaw closing muscles
   1. Masseter
   2. Temporalis
   3. Medial pterygoid
B. Jaw opening muscles
   1. Anterior digastric
   2. Lateral pterygoid

Masseter

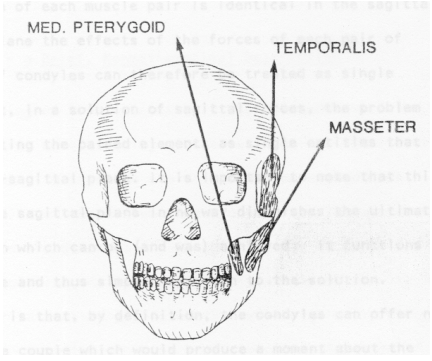


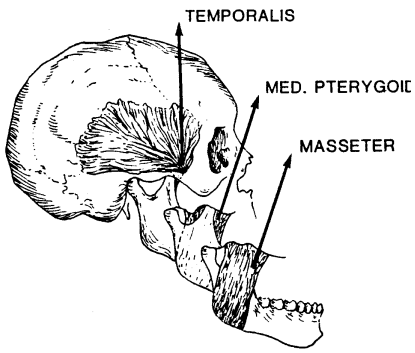
Origin:
zygomatic process of the maxilla and inferior border of zygomatic arch

Insertion:
angle of the mandible inferior, lateral side of ramus

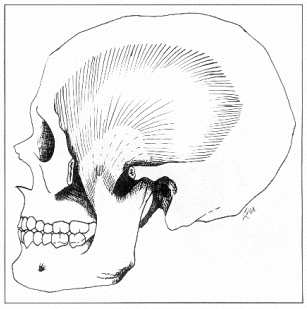
Innervation:
masseteric nerve

Function:
elevate mandible





Temporalis



Origin:
temporal fossa and temporal fascia

Insertion:
coronoid process of the mandible

Innervation:
temporal nerve

Function:
elevate mandible

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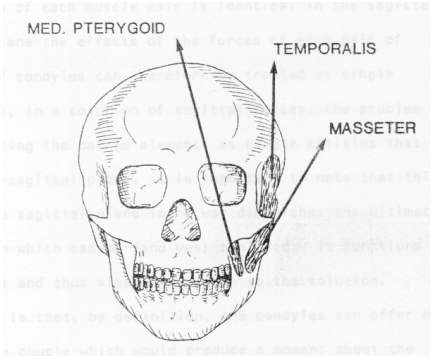

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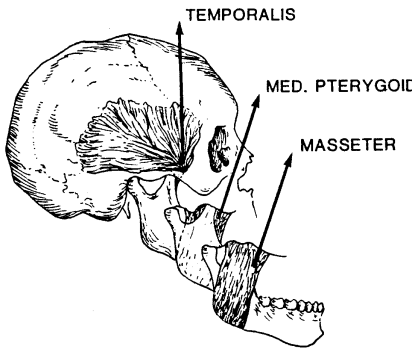

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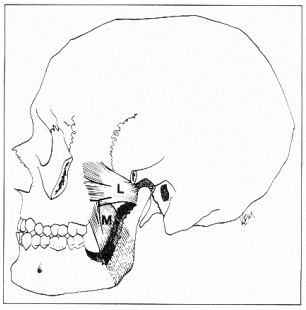
Medial Pterygoid



Origin:
pterygoid fossa and medial surface of lateral pterygoid plate

Insertion:
ramus and angle of the mandible

Innervation:
medial pterygoid nerve

Function:
elevate mandible

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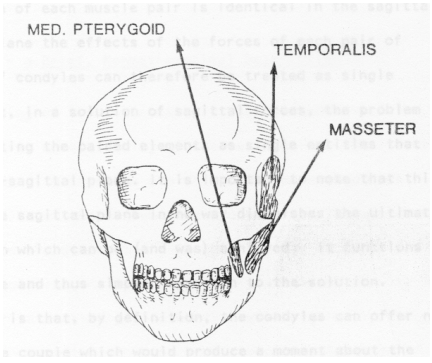

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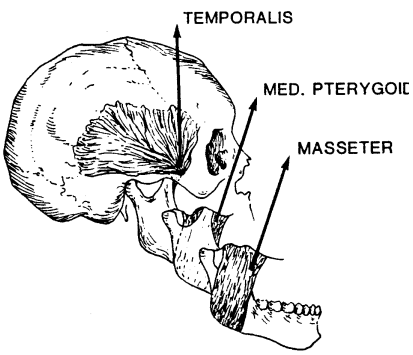

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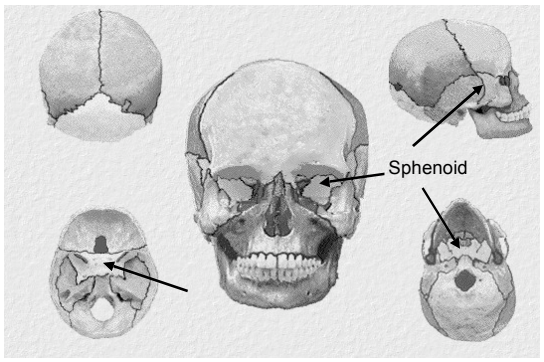

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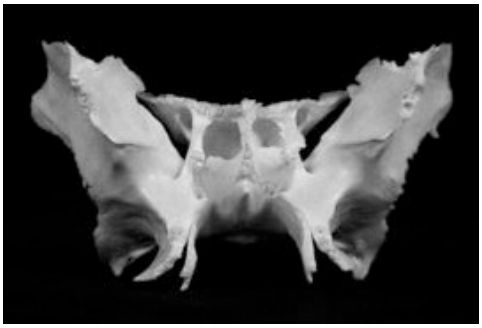

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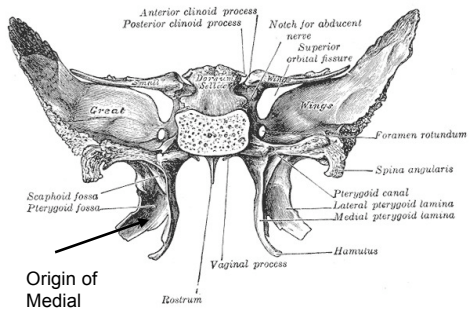

Sphenoid bone. Upper and posterior surfaces.

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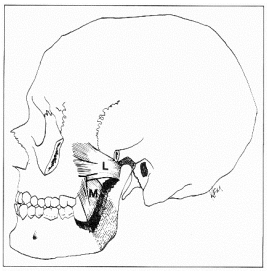
Lateral Pterygoid -- Inferior Head



Origin:
lateral surface of lateral pterygoid plate

Insertion:
anterior neck of the mandible

Innervation:
branch of masseteric or buccal nerve

Function:
pull condyle and disk along the eminence

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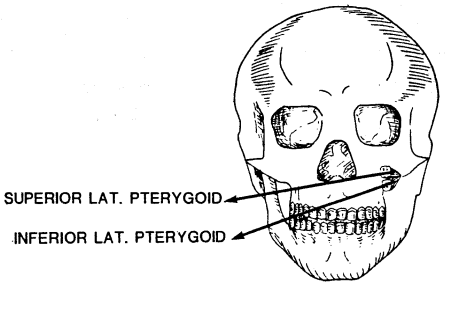

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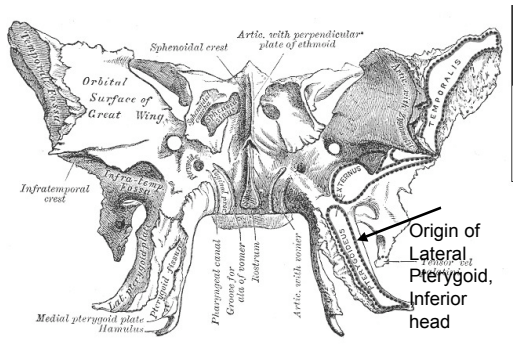
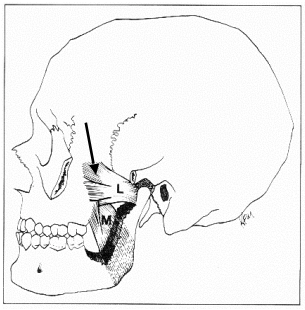


Sphenoid bone. Anterior and inferior surfaces.

Lateral Pterygoid -- Superior Head

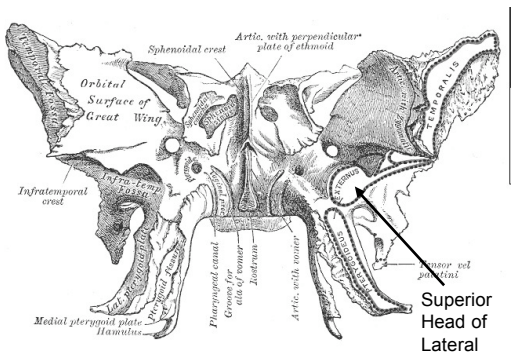


Origin:
infratemporal fossa of greater sphenoid wing

Insertion:
anterior neck of the mandible

Innervation:
branch of masseteric or buccal nerve

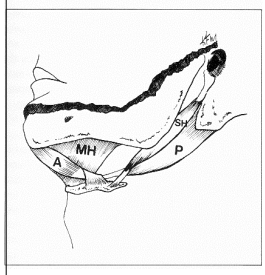
Function:
pull condyle and disk along the eminence



Superior Head of Lateral Pterygoid

Sphenoid bone. Anterior and inferior surfaces.

Digastric

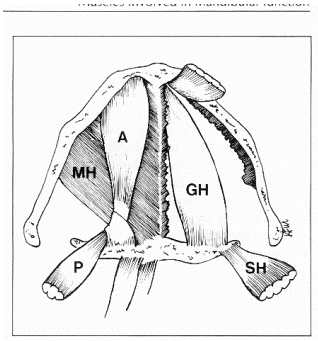


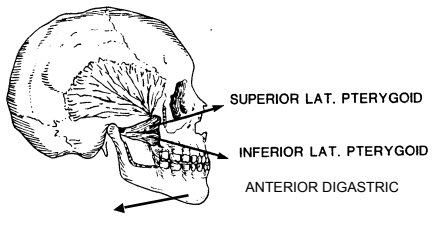
Origin:
posterior digastric mastoid notch of temporal bone

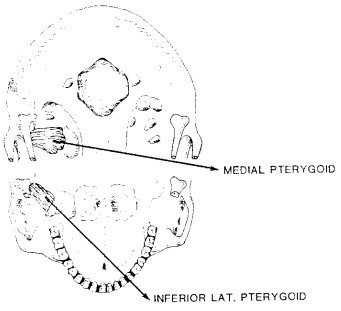
Insertion:
anterior digastric lingual, inferior border of the mandible

Innervation:
Posterior digastric--facial nerve
Anterior digastric--mylohyoid, mandibular nerve

Function:
Lower mandible, raise hyoid







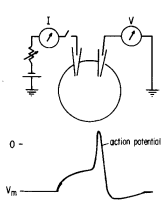
Topics to be Covered

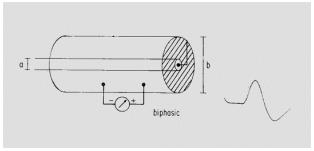
I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Some trigeminal reflexes
V. Selected dental controversies

III. Electromyography

A. Mechanism
B. Electrodes
C. Electronics
D. Caveats
E. Strengths

A. MECHANISM: Muscle Action Potentials

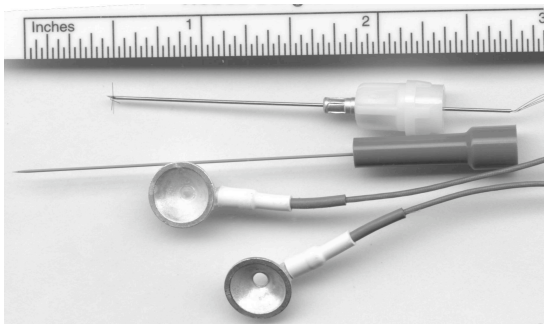




Across membrane: 90 mV Extracellular: about 90 μV

EMG signal is attenuated at the skin by about 1000

B. ELECTRODES



Caveats

A. Electrical activity must be calibrated to be directly related to muscle force.
B. Jaw muscles are redundant: six jaw closers, and they all are active in closing. (You cannot control the muscles independently. The forces on the jaw must satisfy Newton's equations.)

Determinants of Muscle Force

Item	Seen in EMG?
A. Recruitment	Yes
B. Frequency	Yes
C. Length	No
D. Velocity	No

Strengths of Electromyography

A. Know precisely when muscle is active.
B. Know roughly how active.
C. Insight into activity of motor neuron.

Topics to be Covered

I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Some trigeminal reflexes
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IV. Some trigeminal reflexes

A. Jaw closing reflex
B. Jaw opening reflex
C. Blink reflex
D. Tongue reflex
E. Gagging
F. Swallowing
G. Modulating influences

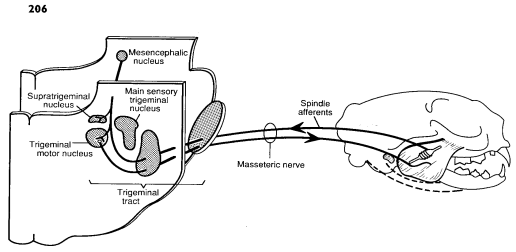
THE BIG PICTURE

FUNCTION	EXAMPLE	NEURAL CIRCUIT	LOCATION
Postural	Jaw jerk	Reflex	Brainstem
Protection	Gagging, Jaw opening	Reflex	Brain stem
Rhythmic activity	Chewing, Breathing, Walking	Pattern generator	Brain stem
Complex function	Speech		Cortex

Types of Reflexes

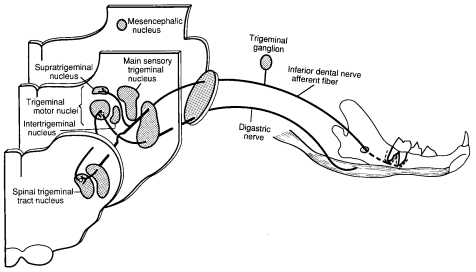
1. Postural
2. Protective
3. Cardiovascular
4. Respiratory
5. Digestive
6. Humoral

The Jaw Jerk Reflex (Postural)



R.M. Bradley, Figure 10-12

The Jaw Opening Reflex (Protective)



R.M. Bradley, Figure 10-13

V. Selected Controversies

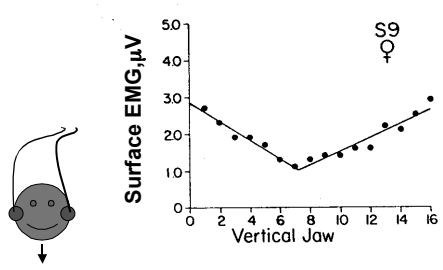
A. Rest position: passive elasticity vs. active contraction
B. Mastication: alternating reflexes vs. central pattern generator
C. Electronic devices for TMD diagnosis
D. Myofascial pain and trigger points

A. Rest position hypotheses

1. Passive elasticity
2. Active contraction
   a. Stretch reflex
   b. TMJ receptors
   c. Airway patency

Rest Position: Evidence

Passive Elasticity	Active Contraction
Length-tension curve	Sleep in chair
Negative EMG search	MN inhibition in sleep
	Positive needle EMG
	Positive surface EMG



Vertical Jaw Opening, mm

B. Mastication hypotheses

A. Hypotheses
   1. Alternating reflexes (Sherrington, 1917)
   2. Central pattern generator (Lund, 1971)
B. Significance: part of the theme, "Be skeptical and be critical"

Outline

1. Dental significance
2. Data to be explained
3. Reflex theory for mastication
4. Central pattern generator

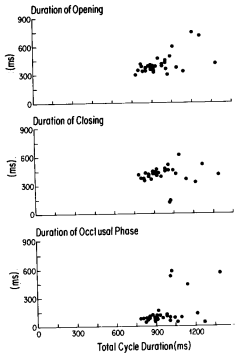
1. Dental Significance

A. Your system
B. Understand mechanisms
C. A plea for skepticism

2. Data to be explained

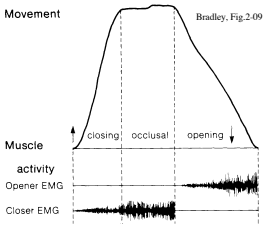
A. Muscle activity
   1. Closers and openers alternate
   2. Cycle duration about one second
B. Jaw motion
   1. Parts of cycle
   2. Closing, occlusal, & opening phases
   3. Variability

Data from one subject

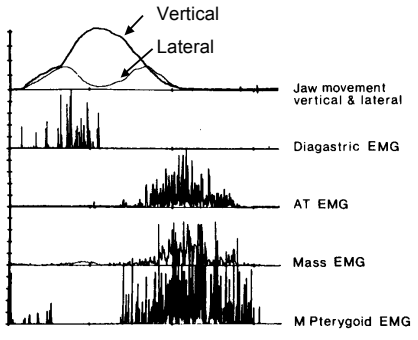


Average: 1060 ms

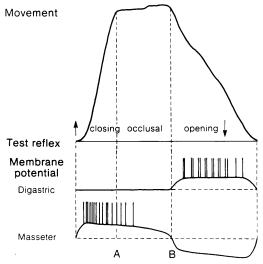
Plesh, Bishop, & McCall, Exper. Neurol. 99: 326, 1988



Observations:
1. Three phases to jaw motion: closing, occlusion, opening
2. Occlusal phase substantial
3. Cycle time about one second
4. Activity of closers and openers alternate



Plesh, Bishop, & McCall, Exper. Neurol. 99: 326, 1988



Observations:
1. No IPSP in motor neurons of jaw opener muscle
2. Jaw opening reflex inhibited during closing
3. Both EPSP & IPSP in motor neurons of jaw closer muscle
4. Jaw closing reflex inhibited during opening

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Reflex theory for mastication

A. Context
   1. Sherrington
   2. Reflexes
   3. Paradigm
B. Experiment
   1. Decerebrate
   2. Observe reflexes

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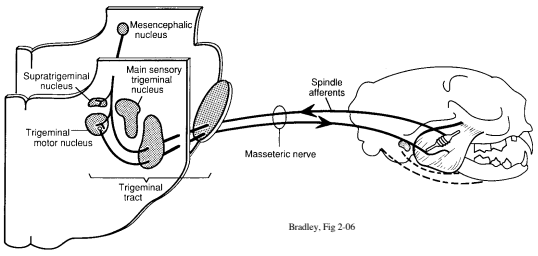
Jaw closing reflex



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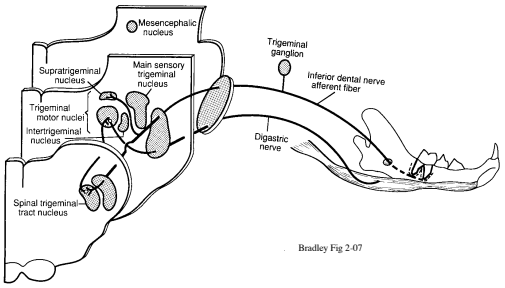
Jaw opening reflex in the cat



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B. Experiment
   1. Decerebrate
   2. Observe reflexes
      a. Jaw closing reflex
      b. Jaw opening reflex
   3. Interpretation: basis of chewing (1917)

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C. Problems (not seen at the time)
   1. Reflex loop times
      a. Jaw Closing ~15 ms
      b. Jaw Opening ~ 20 ms
      c. But cycle time ~ 1000 ms
   2. Length of occlusal phase
      a. Expect short if reflex
      b. But, in fact, it is long
   3. Effect of deafferentation
      a. Would abolish reflexes
      b. But efferent pattern continues
   4. Reflexes inhibited

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D. Reasons for continued belief (into '70's)
   1. Elegant simplicity of theory
   2. Faith in paradigm of reflexes
   3. Stature of Sherrington

E. Plea for your skepticism. Ask questions.
   1. What experiment would disprove theory?
   2. What alternative hypothesis would be plausible?

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Central Pattern Generator

A. Approach: successive approximations

B. Reference:

James P. Lund,

Mastication and its control by the brain stem,

CRC Critical Reviews in Oral Biology and Medicine, 2: 33-64, 1991.

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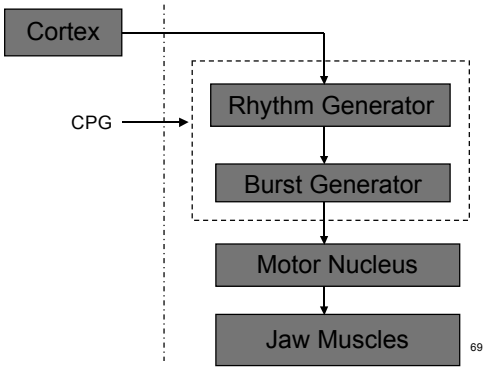
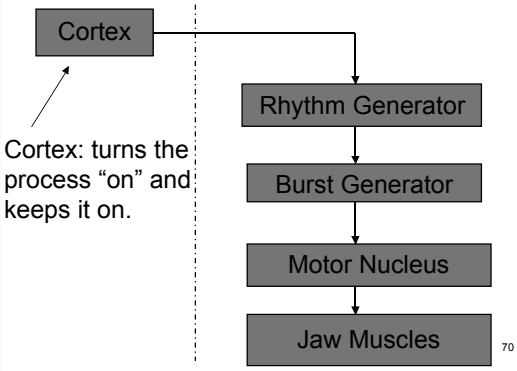
Central Pattern Generator: First Approximation



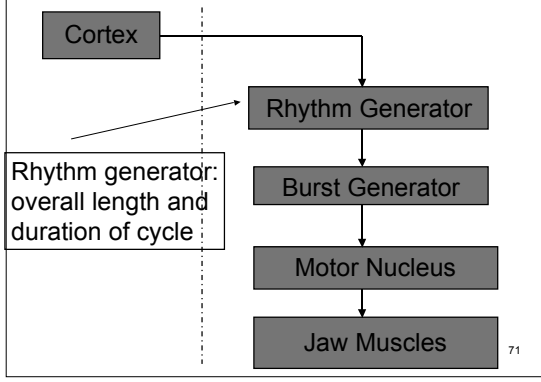
69

Central Pattern Generator: Overall Roles

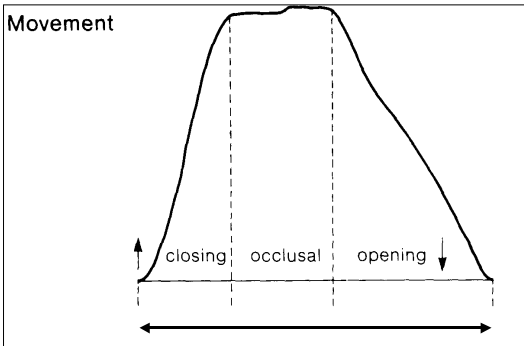


70

Central Pattern Generator: Overall Roles



71



Rhythm generator sets this interval.

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Central Pattern Generator: Overall Roles

Cortex

Rhythm Generator

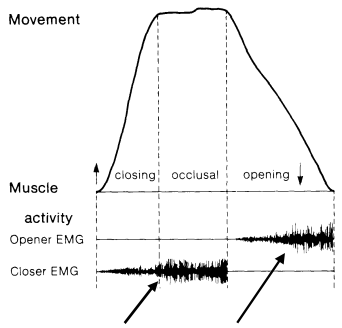
Burst Generator

Motor Nucleus

Jaw Muscles

Burst generator: duration and pattern within the overall cycle

73



Burst generator controls these durations.

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Central Pattern Generator: Overall Roles

Cortex

Rhythm Generator

Burst Generator

Motor Nucleus

Jaw Muscles

Motor nucleus: drive the individual muscles

75

Central Pattern Generator: Overall Roles

Cortex

Rhythm Generator

Burst Generator

Motor Nucleus

Jaw Muscles

Jaw muscles: convert the neural activity to force on the mandible

76

CPG: Second Approximation

Cortex

Rhythm Generator

Evidence for rhythm generator:

1. **Correct anatomical projections from cortex.**
2. **Electrical stimulation of cortex leads to rhythmic activity.**
3. **That stimulation can be random or regular.**
4. **Lesions of pathway abolish rhythmic activity.**
5. **Rhythmic activity seen in paralyzed animal.**

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CPG: Second Approximation

Cortex

Rhythm Generator

Nucleus reticularis paragigantocellularis

PGC

GCr

Nucleus reticularis gigantocellularis

GCc

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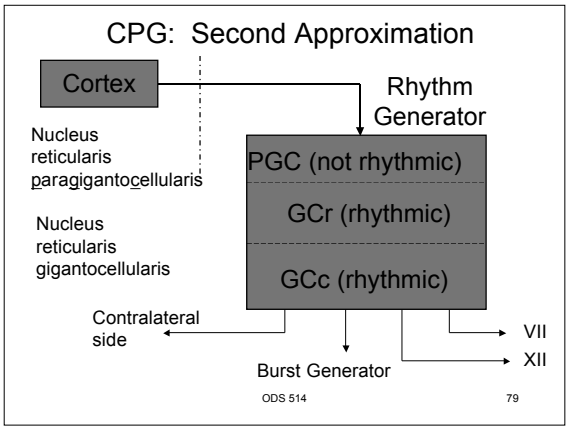
CPG: Second Approximation
Cortex
Rhythm Generator
Nucleus reticularis paragigantocellularis
PGC (not rhythmic)
GCr (rhythmic)
Nucleus reticularis gigantocellularis
GCc (rhythmic)
Contralateral side
VII
XII
Burst Generator
ODS 514
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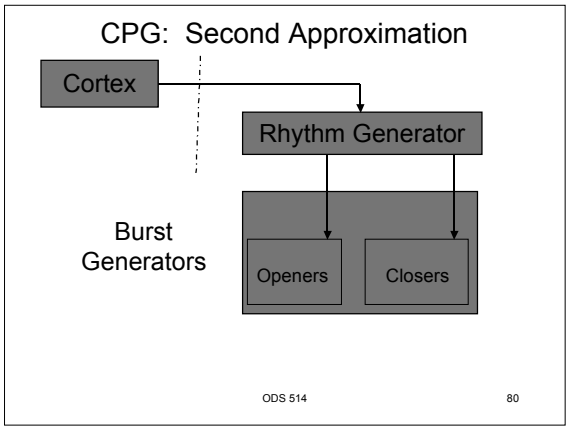
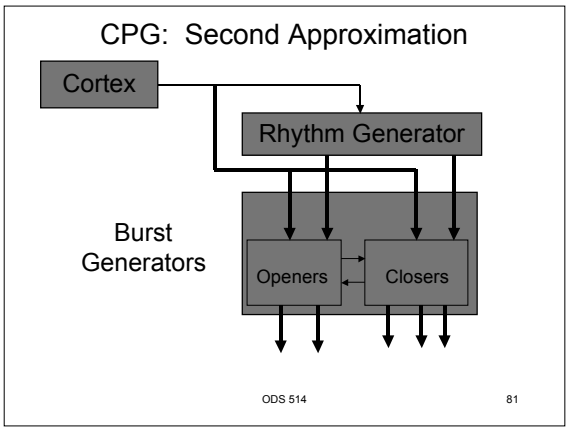
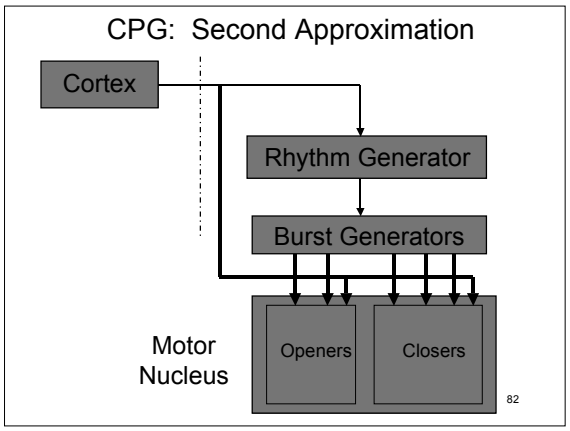
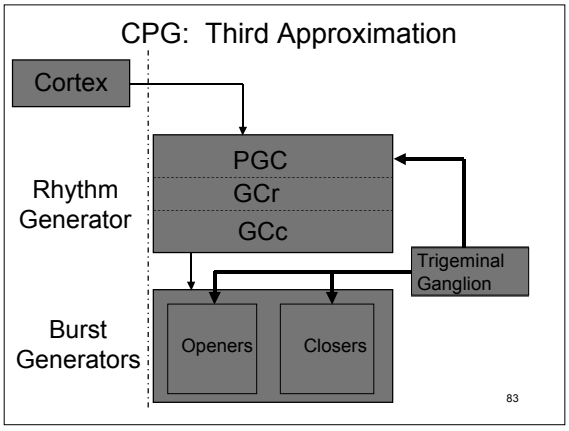
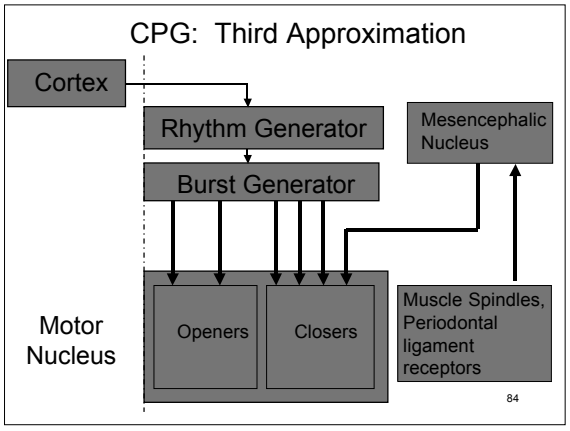

CPG: Second Approximation
Cortex
Rhythm Generator
Burst Generators
Openers
Closers
ODS 514
80


CPG: Second Approximation
Cortex
Rhythm Generator
Burst Generators
Openers
Closers
ODS 514
81


CPG: Second Approximation
Cortex
Rhythm Generator
Burst Generators
Motor Nucleus
Openers
Closers
82


CPG: Third Approximation
Cortex
PGC
GCr
GCc
Rhythm Generator
Trigeminal Ganglion
Burst Generators
Openers
Closers
83


CPG: Third Approximation
Cortex
Rhythm Generator
Mesencephalic Nucleus
Burst Generator
Motor Nucleus
Openers
Closers
Muscle Spindles, Periodontal ligament receptors
84

Summary of central pattern generator

Parts and roles:

- Cortex -- turn on and keep on
- Rhythm Generator -- overall interval
- Burst Generator -- intervals within cycle
- Motor Nucleus -- drive individual muscles
- Muscles -- convert neural activity to force
- Sensory feedback -- adapt to changes

C. Electronic devices for TMD diagnosis

Hypotheses:

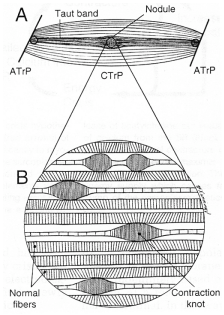
1. Resting EMG greater in TMD patients
(No convincing evidence)

2. Jaw position differs in TMD patients
(No convincing evidence)

Topics to be Covered

I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Some trigeminal reflexes
V. Selected dental controversies
   A. Rest position
   B. Mastication
   C. Electronics for TMD diagnosis
   D. Myofasical pain and trigger points

Myofascial Trigger Points



- **First described by Travell (1942)**
- **Hyperirritable spots located in taut bands of skeletal muscle**
- **Range from 2 to 5 mm in diameter**
- **Two types**
  - **Active TrP - gives referred pain**
  - **Latent TrP - gives local pain**

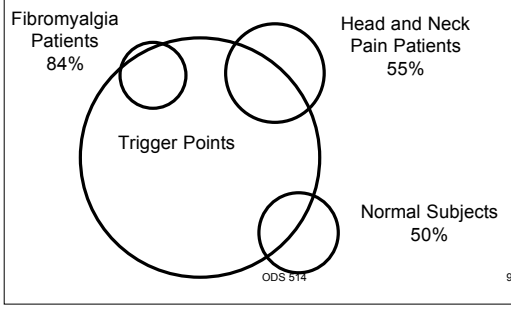
Controversies

1. Existence of trigger points (reliability)
2. Existence of electrical activity
3. Mechanism leading to electrical activity
4. Treatment

Three lines of evidence for existence

1. Reliability improved by training
2. Persistence of clinical observations
3. Epidemiology

Epidemiology of Trigger Points



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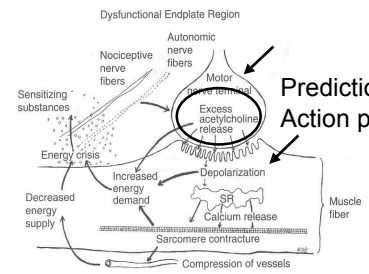
Simons' Hypothesis: Dysfunctional Neuromuscular Junction



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Electrical Activity from Trigger Points

A. FIRST REPORT (Weeks and Travell, **1957)**

B. NEGATIVE REPORTS
1. Kraft *et al.* (1968)
2. Zidar et al. (1990)
3. Durette *et al.* (1991)

C. POSITIVE REPORTS
1. Hubbard and Berkoff (1993)
2. McNulty *et al.* (1994)
3. Hong and Simons (1998)
4. Chen *et al.* (1998)
5. Chung, Ohrbach, & McCall (2004)
6. Chung, Ohrbach, & McCall (2006)

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Prediction #2

EMG amplitude will depend on location and depth of the monopolar needle.

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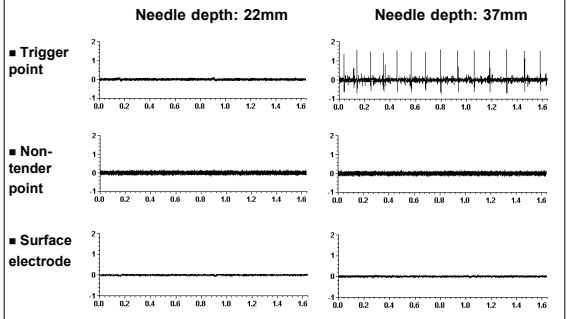

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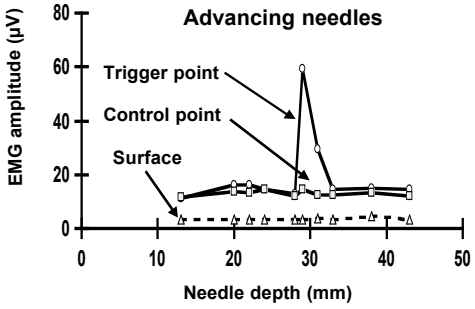
EMG and Needle Depth



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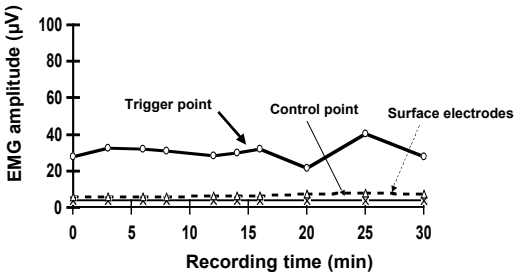
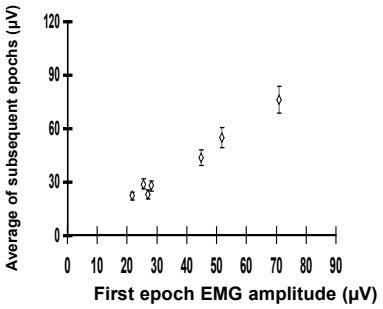
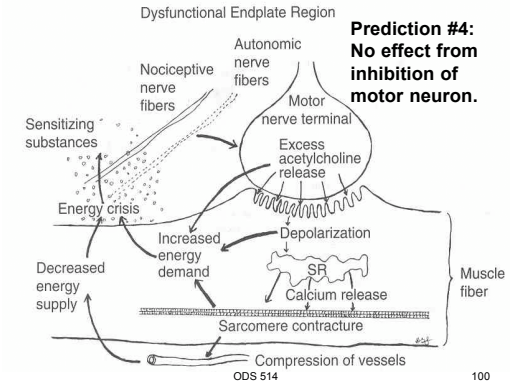
Prediction #1
Action potentials. OK.
Prediction #2
EMG amplitude will depend on location and depth of the monopolar needle.
Prediction **#3**
EMG amplitude will remain stable over an extended recording time.

EMG and Recording Time

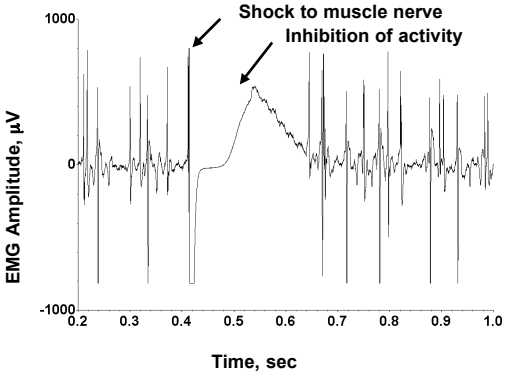


Stability of EMG amplitudes over recording periods





Prediction #4: No effect from inhibition of motor neuron.



In summary…

A. Trigger points show electrical activity
B. Narrow range of depths
C. Reliable over time
D. Activity inhibited by shock to nerve (thus, activity depends on motor neurons)
E. Speculation: acetylcholine hypothesis needs revision

Summary

I. Properties of muscle
II. Muscles of mandibular function
III. Electromyography
IV. Two trigeminal reflexes
V. Selected dental controversies

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