

Chapter 8. Muscular System

Part 1. Muscle-Tissue Types, Contraction & Functional Classification

1 Learning Objectives

After studying this section you will be able to ...

1. **Compare structural and functional features** of skeletal, cardiac, and smooth muscle tissues.
2. **Explain the sliding-filament mechanism** and outline each step of excitation-contraction coupling.
3. **Classify skeletal muscles** by orientation, action, and fibre-type composition, and relate each class to movement efficiency and rehabilitation dosing.
4. **Apply muscle-mechanics principles** (length-tension, force-velocity, motor-unit recruitment) to physiotherapy assessment and exercise prescription.

2 Muscle-Tissue Types

Characteristic	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Location	Attached to skeleton (via tendons, aponeuroses)	Myocardial wall, proximal great vessels	Walls of hollow organs & vessels, arrector pili, iris
Fibre appearance	Long, cylindrical, multinucleate, striated	Branched, single nucleus, striated , intercalated discs	Spindle-shaped, single nucleus, non-striated
Control	Voluntary (somatic)	Involuntary (autorhythmic + autonomic)	Involuntary (autonomic + hormones + local factors)
Excitation speed	Fast (1-5 ms)	Intermediate (10-15 ms)	Slow (50-100 ms)
Conduction	Motor end-plate → T-tubules	Gap junctions + T-tubules (ventricles)	Gap junctions (unitary) / none (multi-unit)
Fatigue profile	Variable; depends on fibre type	Fatigue-resistant	Highly fatigue-resistant
Key clinical notes	Hypertrophies with overload, atrophies with disuse; prone to strains	Ischaemia & arrhythmias major physio concerns	Hypertonicity in asthma, bowel, vascular spasm - target for breathing & relaxation training

PT Pearl: Cardiac muscle's refractory period (~250 ms) prevents tetany, securing rhythmic pumping; hence high-frequency electrical stim parameters used for limb muscles are unsafe for the heart.

3 Microscopic Anatomy & Contraction Mechanics

3.1 From Macro- to Micro-structure

Muscle → Fascicle → Fibre (cell) → Myofibril → Sarcomere → Filaments

- **Connective-tissue sheaths:**

Epimysium (whole muscle) → *Perimysium* (fascicle) → *Endomysium* (fibre) - transmit force to tendon; sites of myofascial restrictions.

- **Sarcomere components (Z-line → Z-line):**

- Thin filaments = **actin**, tropomyosin, troponin.
- Thick filaments = **myosin** with ATPase heads.
- Elastic filaments = **titin** provide passive tension.

3.2 Excitation-Contraction Coupling

1. **Action potential** travels down α -motor neurone.
2. **ACh release** at neuromuscular junction \rightarrow sarcolemma depolarises.
3. **T-tubule AP** triggers Ca^{2+} release from sarcoplasmic reticulum (SR).
4. **Ca^{2+} binds troponin-C** \rightarrow tropomyosin shifts \rightarrow myosin-binding sites exposed.
5. **Cross-bridge cycling** (attach-powerstroke-detach-re-cock) driven by ATP hydrolysis.
6. **Relaxation:** Ca^{2+} pumped back into SR (requires ATP); tropomyosin re-blocks actin.

Energy cost note: In isometric endurance holds the cross-bridge cycling slows, but SR pumps still consume ATP – important for fatigue education.

4 Muscle-Classification Schemes

Dimension	Sub-classes	Functional Implication
Architecture	Parallel/Fusiform (biceps brachii) – greater excursion & velocity; Pennate (rectus femoris, soleus) – higher physiological cross-section \rightarrow force; Circular (orbicularis oris); Convergent (pectoralis major)	Guides exercise selection: pennate for strength loading, fusiform for speed drills
Role in Movement	Agonist (prime mover), Antagonist, Synergist, Fixator/Stabiliser	EMG biofeedback identifies overactive synergists in poor motor patterns
Joint Crossing	Mono-articular vs Bi-articular (hamstrings, gastrocnemius)	Bi-articular muscles prone to passive insufficiency – cue stretching order
Fibre-Type Composition	Type I (slow oxidative), Type IIa (fast oxidative-glycolytic), Type IIx (fast glycolytic)	Determines endurance vs power dosing; elderly show type II atrophy first
Leverage Class	Class-I/II/III levers (EFL/ELF/FEL)	Explains why biceps curl has mechanical disadvantage yet large ROM

5 Muscle Mechanics: Key Principles for Physiotherapy

Principle	Take-home Message	Practical Example
Length-Tension	Maximal active force at $\sim 1.2 \times$ resting length (optimum myofilament overlap)	Use slight hip flexion when MMT quadriceps for maximal output
Force-Velocity	Concentric force \downarrow as velocity \uparrow ; eccentric force \uparrow up to $\sim 1.5 \times$ isometric	Eccentric hamstring training (Nordic curls) builds high force with lower metabolic cost
Motor-Unit Recruitment (Henneman's size principle)	Type I units fire first; high-threshold Type II recruited with \uparrow intensity	Gradually load in neuro-re-ed to avoid spastic overflow
Passive Tension	Titin & connective tissues generate nonlinear resistance when stretched	Static stretch held ≥ 30 s taps into viscoelastic creep

6 Structure-Function-Clinical Correlations

Clinical Scenario	Underlying Muscle Principle	Physiotherapy Action
Delayed-onset muscle soreness (DOMS) after eccentric descent	Greater sarcomere strain + micro-tears	Progressive eccentric dosing; cryotherapy 24 h post
Myocardial infarction limits peak VO_2	Cardiac muscle necrosis reduces stroke volume	Begin phase-I cardiac rehab ≤ 3 days if stable; RPE ≤ 11
Asthma bronchospasm	Smooth-muscle hyper-contraction around bronchioles	Teach pursed-lip breathing, diaphragmatic control

7 Self-Check Quiz (answers below)

1. Name two structural differences between skeletal and cardiac muscle that influence fatigue resistance.
2. Why can't cardiac muscle produce a tetanic contraction?
3. Which muscle architectural type produces the greatest force per CSA and why?
4. During a rapid concentric biceps curl, is force production ↑ or ↓ compared with a slow curl? Explain.
5. A hamstring MMT is strongest with the hip slightly flexed. Which mechanical principle is illustrated?

Answers

1. Cardiac fibres are single-nucleated with abundant mitochondria & myoglobin, and intercalated discs that synchronise contractions; skeletal fibres may have fewer energy organelles (especially fast fibres) and lack intercellular Ca^{2+} sharing, so they fatigue faster.
2. Cardiac muscle's long absolute refractory period (≈ 250 ms) prevents summation of action potentials, eliminating tetanus.
3. **Pennate muscles**—their oblique fibre angle packs more fibres into a given area, increasing physiological cross-section and thus maximal force.
4. Force production **decreases** at higher concentric velocities due to the force-velocity inverse relationship (cross-bridges have less time to form).
5. **Length-tension relationship**: a slight stretch aligns actin-myosin overlap optimally, boosting active tension.

8 Suggested Lab / Practical Activities

Activity	Purpose
Electromyography (EMG) Lab	Record activation of agonist vs antagonist during isometric and isotonic tasks; analyse recruitment patterns.
Histology Slide Session	Identify skeletal vs cardiac vs smooth muscle under microscope; note striations & intercalated discs.
Isokinetic Dynamometry	Plot force-velocity curves for quadriceps; relate to rehab progression.

9 Key Take-Home Points

- **Skeletal, cardiac, and smooth muscles share the sliding-filament mechanism** but differ in control, speed, and fatigue profiles—each nuance shapes physiotherapy precautions.
- **Muscle architecture and fibre type determine strength, endurance, and movement precision**; align exercise dosage accordingly.
- **Length-tension and force-velocity principles guide everything from MMT grading to plyometric programming**.
- Effective rehabilitation balances **neural recruitment, metabolic capacity**, and **connective-tissue resilience** for long-term functional gains.

Part 2. Major Skeletal Muscles & Their Functions

1 Learning Objectives

On completing this part, you should be able to ...

1. **Locate and name the principal muscles** of the head, neck, trunk, and limbs.
2. **State each muscle's origin, insertion, nerve supply, and primary action.**

3. **Describe functional synergies** (e.g., force-couples, slings) essential for posture and movement.
4. **Identify common clinical dysfunctions** and outline physiotherapy strategies grounded in muscular anatomy.

2 Head & Neck Muscles

Group	Key Muscles	Origin → Insertion	Nerve	Main Action	PT / Clinical Note
Facial Expression	Frontalis, Orbicularis oculi, Zygomaticus major, Orbicularis oris	Bones / fascia of face → skin Zygomatic arch / temporal fossa / sphenoid → mandible	CN VII (Facial) CN V ₃ (Mandibular)	Non-verbal communication, sphincter control Elevate, protrude, grind mandible	Bell's palsy retraining, Botox sites TMJ mobilisation, bruxism management
Mastication	Masseter , Temporalis, Medial & Lateral pterygoids	Mandible → hyoid	CN V ₃ , VII	Swallowing, speech	Dysphagia therapy
Anterior Neck (Suprahyoid)	Mylohyoid, Digastric	Sternum / scapula → hyoid	Ansa cervicalis (C1-C3)	Depress hyoid	Post-thyroidectomy voice care
Anterior Neck (Infrahyoid)	Sternohyoid, Omohyoid	Manubrium + clavicle → mastoid; Cervical TVPs → plexus	CN XI + C2-C3; Cervical 1-2 ribs	Bilat: flex neck; Uni: rotate opp. side	Forward-head posture correction
Cervical Flexors	Sternocleidomastoid (SCM), Scalenes	C1-C2 → occiput; Cervical SPs → mastoid	Dorsal rami	Postural support, fine head motion	Cervicogenic headache trigger points
Cervical Extensors	Sub-occipitals, Splenius capitis				

3 Trunk Muscles

3.1 Abdominal Wall

Layer	Muscle	O-I	Nerve	Action	Key Function
Superficial	External oblique	Ribs 5-12 → iliac crest, linea alba	Thoraco-abdominal (T7-T11), subcostal	Flex, contralateral rotation trunk	Posterior pelvic tilt
Intermediate	Internal oblique	Thoracolumbar fascia → ribs 10-12, linea alba	T7-L1	Flex, ipsilateral rotation	Forms abdominal "corset"
Deep	Transversus abdominis	Costal cartilages 7-12, fascia → linea alba	T7-L1	Compress viscera	Feed-forward core stabiliser
Vertical	Rectus abdominis	Pubic crest → ribs 5-7, xiphoid	T7-T12	Trunk flexion	Sit-ups, cough force

3.2 Back (Posterior)

Layer	Muscles	Nerve	Primary Role
Superficial	Trapezius, Latissimus dorsi, Levator scapulae, Rhomboids	CN XI (Trap); Dorsal scapular; Thoracodorsal	Scapular/humeral positioning
Intermediate	Serratus posterior sup/inf	Intercostals	Respiratory accessory
Deep ("Erector Spinae")	Iliocostalis, Longissimus, Spinalis	Posterior rami	Trunk extension, posture
Deeper ("Transversospinales")	Multifidus, Rotatores, Semispinalis	Posterior rami	Segmental stability & rotation

Layer	Muscles	Nerve	Primary Role
Minor Deep	Interspinales, Intertransversarii	Posterior rami	Proprioception, fine control

Core Sling: *Transversus abdominis* + *Multifidus* + *Diaphragm* + *Pelvic floor* → anticipatory activation before limb movement; rehabbing LBP focuses here.

4 Upper-Limb Muscles

Region	Major Muscles	Actions (prime)	Clinical Focus
Shoulder Scapulothoracic	Serratus anterior, Upper/lower trapezius	Upward rotation, protraction	Prevent impingement; winging test
Glenohumeral Prime Movers	Deltoid (multi-pennate), Pectoralis major, Latissimus dorsi	Abd, flex(IR)/add, ext(IR)	Strength balance for posture
Rotator-Cuff (SITS)	Supraspinatus, Infraspinatus, Teres minor, Subscapularis	Stabilise humeral head; abd (supraspinatus); ER (infra, TM); IR (subscap)	Post-RC repair protocol
Arm (Anterior)	Biceps brachii, Brachialis, Coracobrachialis	Elbow flex (supination), pure flexor, shoulder flex/add	Tendinopathy management
Arm (Posterior)	Triceps brachii	Elbow extension	Push-up progression
Fore-arm Flexor Compartment	Pronator teres, FCR, Palmaris longus, FDS, FDP, FPL	Wrist/finger flex, pronation	Grip-strength rehab
Fore-arm Extensor Compartment	ECRL/B, ECU, ED, EPL, EPB	Wrist/finger ext, thumb ext	Lateral epicondylitis care
Intrinsic Hand	Thenar (APB, FPB, OP), Hypotenar, Interossei, Lumbricals	Thumb opposition, fine motor, MCP flex/IP ext	Dexterity retraining post-stroke

5 Lower-Limb Muscles

Region	Muscle Group	Key Actions	PT Highlight
Gluteal	Gluteus maximus (hip ext/ER), Gluteus medius/minimus (abd, IR)	Pelvic stability in SLS	Trendelenburg correction
Lateral Rotators	Piriformis, Obturators, Gemelli, Quadratus femoris	Hip ER	Piriformis syndrome stretch
Anterior Thigh	Quadriceps femoris (RF, VL, VM, VI)	Knee ext; RF hip flex	Post-ACL strength timeline
Medial Thigh	Adductor longus/brevis/magnus, Gracilis, Pectenae	Hip add	Groin strain rehab
Posterior Thigh	Hamstrings (Biceps fem., Semitend., Semimemb.)	Knee flex, hip ext	Eccentric injury prevention
Leg - Anterior	Tibialis anterior , EDL, EHL	Dorsiflexion, toe ext	Foot-drop NMES
Leg - Lateral	Fibularis longus/brevis	Eversion, plantarflex assist	Peroneal strain support
Leg - Posterior Superficial	Gastrocnemius, Soleus, Plantaris	Plantarflex; Gc knee flex	Calf-raise progressions
Leg - Posterior Deep	Tibialis posterior, FDL, FHL, Popliteus	Inversion, toe flex, unlock knee	Medial arch support
Intrinsic Foot	Abd hallucis, FDB, Lumbricals, Interossei	Toe posture, arch support	Barefoot strengthening

Lower-Crossed Posture: Weak gluteus maximus/abdominals + tight hip-flexors/erector spinae → anterior

pelvic tilt; target with glute bridging + hip-flexor stretch.

6 Self-Check Quiz (Answers immediately below)

1. **Which muscle is the prime upward rotator of the scapula and why is this motion vital during overhead reach?**
2. **Name the deep core muscle whose anticipatory activation precedes limb movement.**
3. **What nerve innervates the thenar eminence, and what functional loss occurs if it is injured?**
4. **Which two muscles form the 'stirrup' under the foot's medial arch?**
5. **During gait, what is the primary role of the tibialis anterior in initial contact?**

<details> <summary>Answers</summary>

1. **Serratus anterior (with upper & lower trapezius);** upward rotation clears the acromion, preventing shoulder impingement during overhead elevation.
2. **Transversus abdominis.**
3. **Median nerve;** loss of thumb opposition and weakening of precision grip.
4. **Tibialis anterior** (insertion medial cuneiform & MT I) and **Fibularis longus** (crosses under foot to same area) create the stirrup supporting the arch.
5. **Eccentric control of plantarflexion (foot-slap prevention) and maintenance of ankle in neutral for heel strike.**

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7 Suggested Lab / Practical Activities

Activity	Outcome
Surface EMG Mapping of rotator-cuff vs deltoid during abduction	Identify timing & synergy deficits
Palpation Circuit – mark gluteus medius, TFL, piriformis, and hamstring tendons	Landmarks for dry needling or taping
Core Sling Activation – ultrasound or pressure biofeedback to cue Transversus abdominis	Teach feed-forward stabilization
Gait Lab – correlate EMG of tibialis anterior & gastrocnemius with ground-reaction force curves	Adjust orthotic prescription

8 Key Take-Home Points

- Major muscle groups work in **integrated chains**, not isolation—rehab must follow these synergies.
- **Accurate landmark knowledge** (origins/insertions) guides palpation, manual therapy, and exercise cueing.
- **Nerve supply awareness** is critical for diagnosing weakness patterns and selecting electrical-stim parameters.
- Functional outcomes hinge on **balance between opposing groups** (e.g., scapular force-couple, pelvic tilt control).