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.

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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.

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3 Microscopic Anatomy & Contraction Mechanics

3.1 From Macro- to Micro-structure

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Muscle → Fascicle → Fibre (cell) → Myofibril → Sarcomere → Filaments
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- **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 → sarcolemma depolarises.
3. **T-tubule AP** triggers Ca^{2+} release from sarcoplasmic reticulum (SR).
4. **Ca^{2+} binds troponin-C** → tropomyosin shifts → 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.

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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 → 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

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5 Muscle Mechanics: Key Principles for Physiotherapy

Principle	Take-home Message	Practical Example
Length–Tension	Maximal active force at ~ 1.2 × resting length (optimum myofilament overlap)	Use slight hip flexion when MMT quadriceps for maximal output
Force–Velocity	Concentric force ↓ as velocity ↑; eccentric force ↑ up to ~1.5 × 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 ↑ 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

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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

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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.

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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.

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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.**

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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.

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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	CN VII (Facial)	Non-verbal communication, sphincter control	Bell's palsy retraining, Botox sites
Mastication	**Masseter**, Temporalis, Medial & Lateral pterygoids	Zygomatic arch / temporal fossa / sphenoid → mandible	CN V_3 (Mandibular)	Elevate, protrude, grind mandible	TMJ mobilisation, bruxism management
Anterior Neck (Suprahyoid)	Mylohyoid, Digastric	Mandible → hyoid	CN V_3, VII	Swallowing, speech	Dysphagia therapy
Anterior Neck (Infrahyoid)	Sternohyoid, Omohyoid	Sternum / scapula → hyoid	Ansa cervicalis (C1-C3)	Depress hyoid	Post-thyroidectomy voice care
Cervical Flexors	**Sternocleidomastoid** (SCM), Scalenes	Manubrium + clavicle → mastoid; Cervical TVPs → 1-2 ribs	CN XI + C2-C3; Cervical plexus	Bilat: flex neck; Uni: rotate opp. side	Forward-head posture correction
Cervical Extensors	Sub-occipitals, Splenius capitis	C1-C2 → occiput; Cervical SPs → mastoid	Dorsal rami	Postural support, fine head motion	Cervicogenic headache trigger points

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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

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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.

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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), Hypothenar, Interossei, Lumbricals	Thumb opposition, fine motor, MCP flex/IP ext	Dexterity retraining post-stroke

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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, Pectineus	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.

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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

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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).