2 Physical Principles and Kinematics

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An understanding of the physical principles and kinematics involved in the discipline of spine surgery allows the surgeon to appreciate actions and reactions, force vectors, related component vectors, and the movements and/or deformations that they cause, enabling them to apply these concepts to clinical practice.

Learning Objectives

- Understand the importance of the instantaneous axis of rotation (IAR) and the effect of different loads on the IAR.
- Understand Newton's laws of motion and Hooke's law.
- Understand the relationship between stress, bending moment, and section modulus.
- Understand the stress–strain curve, the modulus of elasticity, the moment of inertia, and the coupling effect.

Questions

▸▸ Question 1

Where is the IAR located?

- A. Vertebral body
- B. The location is variable
- C. Facet joint
- D. Pedicle
- E. Neural foramen

▸▸ Question 2

How many degrees of freedom exist around each axis of rotation?

- A. 6
- B. 8
- C. 10
- D. 12
- E. 14

▸▸ Question 3

In the equation $M = F \times D$, what does M represent?

- A. Section modulus
- B. Loading force
- C. Bending moment
- D. Torque
- E. Momentum

▸▸ Question 4

The time rate of momentum of a body is equal in magnitude and direction to the vector sum of the forces acting upon it. Which of the following does this statement best describe?

- A. The law of inertia
- B. Newton's first law of motion
- C. Hooke's law
- D. Newton's second law of motion
- E. Newton's third law of motion

▸▸ Question 5

When rotation is superimposed on translation, what is the resultant component of movement called?

- A. Torque
- B. Bending moment
- C. Helical axis of motion
- D. Momentum
- E. Coupling

▸▸ Question 6

Which of the following statements regarding paradoxical spinal motion is correct?

- A. It is the movement that occurs during the application of flexion only
- B. It is the movement that occurs during the application of extension only
- C. It is the movement that occurs during the application of flexion and extension
- D. It is the movement that occurs during the application of rotation stress only
- E. It is the movement that occurs during the application of flexion, extension, and rotation stress

▸▸ Question 7

Which of the following statements best describes Newton's third law of motion?

- A. If a body is subjected to no net external influence, it has a constant velocity, either zero or nonzero
- B. Interactions between objects result in no net change in momentum
- C. The time rate of momentum of a body is equal in magnitude and direction to the vector sum of the forces acting upon it
- D. Momentum is the product of mass and velocity
- E. An object responds to the summation of the forces applied to it

▸▸ Question 8

Which of the following statements best defines the physical principle of a couple?

- A. The phenomenon by which a movement of the spine along or about an axis obligates another movement along or about another axis (of the Cartesian coordinate system)
- B. A structure acted on by a couple can be kept in equilibrium only by another couple of the same moment and the opposite direction
- C. A couple is a pair of forces applied to a structure that are of equal magnitude and opposite direction, having two lines of action that ultimately coincide
- D. A couple is a pair of forces applied to a structure that are of equal magnitude and opposite direction, having lines of action that are parallel but do not coincide
- E. A couple is a pair of forces applied to a structure that are of unequal magnitude but in the same direction, having lines of action that are parallel but do not coincide

▸▸ Question 9

An axial load applied to a vertebral body at the point of the IAR results, by definition, in an equal (in magnitude) but opposite (in direction) reaction force. This pair of forces may result in deformation or failure of the vertebral body, resulting in which of the following?

- A. Fracture-dislocation
- B. Wedge fracture
- C. Burst fracture
- D. Chance fracture or flexion-distraction fracture
- E. No change in the vertebral body

▸▸ Question 10

For small displacements, the size of the deformation is proportional to the deforming force. Which law does this statement describe?

- A. Hooke's law
- B. Newton's first law of motion
- C. Newton's second law of motion
- D. Newton's third law of motion
- E. The law of superimposition of forces

▸▸ Question 11

A couple is a pair of forces applied to a structure that are of equal magnitude and opposite direction, having lines of action that are parallel but do not coincide. ▸ Fig. 2.1 illustrates a couple consisting of two forces, each of magnitude F, acting upon a structure and separated by a perpendicular distance D. What does the following equation represent?

$$x_1F - x_2F = x_1F - (x_1 + D)F = -DF$$

- A. Bending moment
- B. Section modulus
- C. Momentum
- D. Loading force
- E. Torque

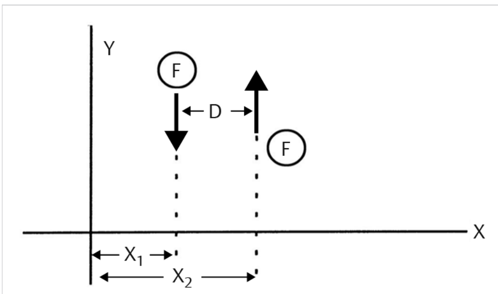

Fig. 2.1 A couple acting on a structure of width D. In this case, translation will not occur, but rotation will occur if the couple is unopposed. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

▸▸ Question 12

In this typical stress–strain curve for a biological tissue, such as a ligament, what does CD represent (see ▸ Fig. 2.2)?
- A. Elastic limit
- B. Elastic zone
- C. Neutral zone
- D. Point of failure
- E. Plastic zone

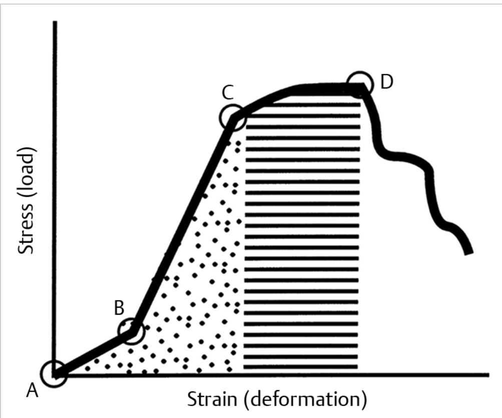

Fig. 2.2 (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

▸▸ Question 13

Elastic modulus or the modulus of elasticity, which is a constant that is characteristic of a given material, is defined by which of the following equations?
- A. Elastic modulus = stress × strain
- B. Elastic modulus = stress/strain
- C. Elastic modulus = strain/stress
- D. Elastic modulus = stress – strain
- E. Elastic modulus = stress + strain

▸▸ Question 14

In the equation $\theta = M/Z$, what does Z represent?
- A. Loading force
- B. Section modulus
- C. Momentum
- D. Bending moment
- E. Torque

▸▸ Question 15

Which of the following is the section modulus proportional to?
- A. Third power of the outer diameter of a screw
- B. Second power of the outer diameter of a screw
- C. Third power of the inner diameter of a screw
- D. Second power of the diameter of the rod
- E. Fifth power of inner diameter of a screw

▸▸ Question 16

Which of the following is stiffness or the moment of inertia (*I*) proportional to?
- A. Second power of the outer diameter of a screw
- B. Third power of the outer diameter of a screw
- C. Fourth power of the diameter of the rod
- D. Fifth power of the diameter of the rod
- E. Fifth power of inner diameter of a screw

▸▸ Question 17

Which of the following statements best describes Newton's first law of motion?
- A. For small displacements, the size of the deformation is proportional to the deforming force
- B. The time rate of momentum of a body is equal in magnitude and direction to the vector sum of the forces acting upon it
- C. For every action, there is an equal but opposite reaction
- D. If a body is subjected to no net external influence, it has a constant velocity, either zero or nonzero
- E. Interactions between objects result in no net change in momentum

▸▸ Question 18

Which of the following phenomena demonstrate the "coupling" effect? Select the best answer.
- A. A pair of forces applied to a structure that are of equal magnitude and opposite direction, having lines of action that are parallel but do not coincide
- B. Spinal rotation
- C. Screw motion when a screw is placed through the bone graft
- D. Spinal burst fracture
- E. Failure of constructs due to use of variable screws in traumatic spine fracture

▸▸ Question 19

How can momentum be best defined? Select the best answer.

- A. Stress/strain
- B. For small displacements, the size of the deformation is proportional to the deforming force
- C. Bending moment/section modulus
- D. Mass × velocity
- E. The ability of an object to resist bending

▸▸ Question 20

The area under the stress–strain curve is proportional to the energy absorbed before failure (point of failure). What is this a measure of?

- A. Resilience
- B. Strength
- C. Stress
- D. Strain
- E. Momentum

Answers

▸▸ Answer 1

Correct answer is B

Forces applied to the spine can be broken down into component vectors. A vector is defined here as a force oriented in a fixed and well-defined direction in three-dimensional space. A force vector may act on a lever (moment arm), causing a bending moment. The bending moment applied to a point in space causes rotation, or a tendency to rotate, about an axis. This axis, regarding the spine, is termed the instantaneous axis of rotation (IAR). The IAR is the axis about which each vertebral segment rotates at any given instant. The word instantaneous is included to emphasize that the axis of rotation varies depending on the loads and forces applied. Multiple factors, such as degenerative disease, fractures, ligamentous injuries, instrumentation and/or fusion placement, and segmental motion, can affect its position (see ▸ Fig. 2.3). The IAR should be considered dynamic. As spinal movement occurs, the IAR of each involved spinal segment moves. The IAR is clinically derived from dynamic radiographs (i.e., flexion and extension radiographs). For example, the IAR is affected by the extent of degeneration and deformation in the spondylotic spine with a lysis of the pedicle (spondylolysis). The IAR migrates rostrally as the extent of the pars defect advances and the wedge deformity progresses.[1] In a sense, the IAR is a fulcrum. For example, if the spine is flexed, all points ventral to the IAR come closer together and all points dorsal to the IAR move farther apart (see ▸ Fig. 2.4). It is important to note that these considerations are clinically important. For example, both cervical spine flexion and extension can decompress the neuroforamina, depending on the location of the IAR. In the case in which the IAR is located in the region of the facet joint, flexion causes neuroforaminal compression and extension causes neuroforaminal decompression. Its location

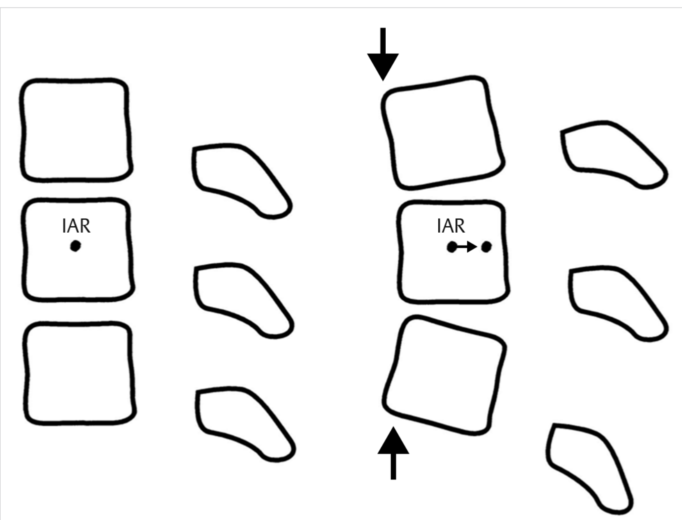

Fig. 2.3 A depiction of an applied bending moment altering the location of the IAR (*dot*) from the (A) preload situation to the (B) postload situation. Because a ventral bending moment was applied, the IAR, as is often the case, moved dorsally. *IAR*, instantaneous axis of rotation. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

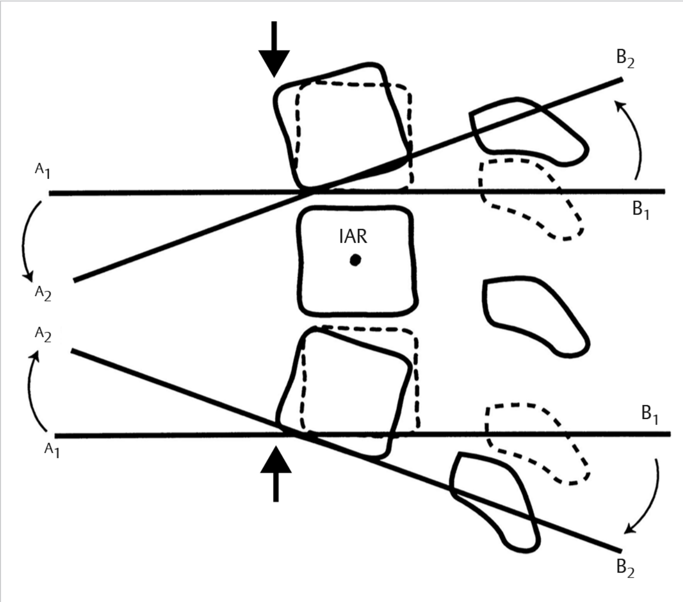

Fig. 2.4 A depiction of the fulcrum-like nature of the IAR (*dot*). If spinal flexion occurs, as depicted, all points ventral to the IAR come closer to one another and all points dorsal to the IAR spread farther apart, as depicted by the curved arrows. A_1 and B_1 designate ventral and dorsal points aligned with the vertebral end plates in the neutral position. A_2 and B_2 represent ventral and dorsal points aligned with the vertebral end plates following flexion. *IAR*, instantaneous axis of rotation. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

is variable, depending on the intrinsic curvature of the spine, as well as other factors,[2,3] which is why option B is correct and options A, C, D, and E are incorrect.

▸▸ **Answer 2**

Correct answer is A

To make things easier, the standard Cartesian coordinate system has been applied to the spine. In this system, there are three axes: the x-, y-, and z-axes. For simplicity, the terms rostral, caudal, ventral, dorsal, right, and left are used. Rotational and translational movements can occur about these axes, resulting in 12 potential movements about the IAR: 2 translational movements along each of the 3 axes (1 in each direction) and 2 rotational movements around each of the axes (1 in each direction). These potential movements may also be considered in terms of degrees of freedom; thus, six degrees of freedom exist about each IAR (see ▶ Fig. 2.5); hence, option A is the correct answer and options B, C, D, and E are incorrect.

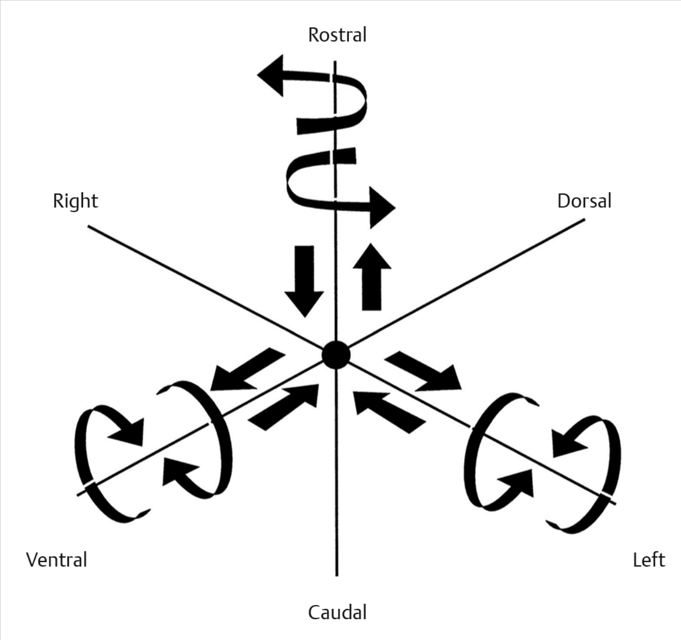

Fig. 2.5 The Cartesian coordinate system with the instantaneous axis of rotation as the center. Translation and rotation can occur in both of their respective directions about each axis. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

▸▸ Answer 3

Correct answer is C

The bending moment (M) is defined as the product of the force (F) applied to the lever arm and the length of the lever arm (D), where D is equal to the perpendicular distance from the force vector to the IAR (see ▶ Fig. 2.1). Therefore, option C is correct, and options A, B, D, and E are incorrect.

▸▸ Answer 4

Correct answer is D

Newton's second law of motion, the law of superimposition of forces, can be stated as: the time rate of momentum of a body is equal in magnitude and direction to the vector sum of the forces acting upon it. In other words, an object responds to the summation of the forces applied to it. Therefore, option D is the correct answer, and options A, B, C, and E are incorrect.

▸▸ Answer 5

Correct answer is C

When rotation is superimposed on translation, the resultant component of movement described by the translational movement vector is called the helical axis of motion. Thus, option C is the correct answer. It is oriented in the direction of the translational movement. A screw motion can be defined, in part, by this parameter. It must be emphasized that the determination of these axes is subject to error. Torque is a measure of the force that can cause an object to rotate about an axis; thus, option A is incorrect. The bending moment (M) is defined as the product of the force (F) applied to the lever arm and the length of the lever arm (D), where D is equal to the perpendicular distance from the force vector to the IAR. The bending moment is effectively the torque applied by the force (circular force). More correctly, torque is a moment with magnitude; thus, option B is incorrect. Momentum is defined as the product of mass and velocity of an object, which is why option D is incorrect. Coupling is defined as the phenomenon by which a movement of the spine along or about an axis obligates another movement along or about another axis; hence, option E is incorrect.

▸▸ Answer 6

Correct answer is E

Paradoxical spinal motion is the unexpected and potentially untoward segmental spinal movement

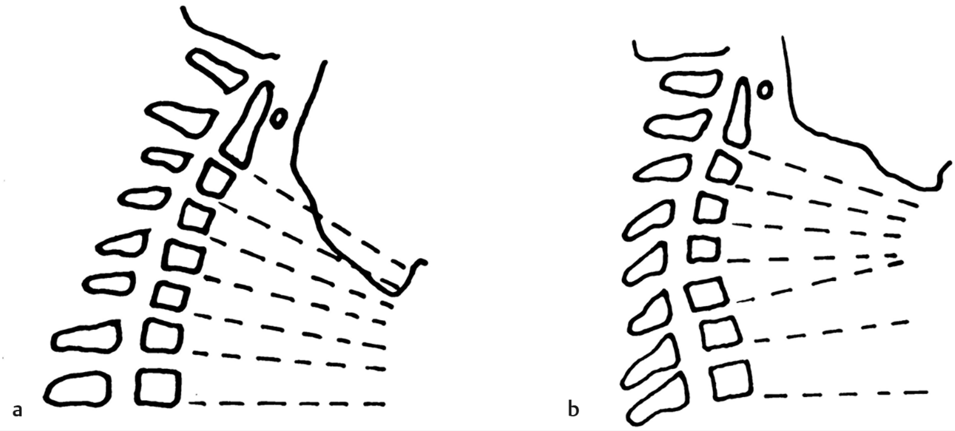

Fig. 2.6 Paradoxical spinal motion is the phenomenon whereby an intended motion, such as flexion, is accompanied by an unintended motion, such as extension, at one or more motion segments. Paradoxical motion can occur when at least two intervertebral discs are suspended between fixation points (either via external splinting or via spinal instrumentation). **(a)** Unobstructed cervical flexion results in uniform segmental flexion in the nonpathologic situation. If restriction of movement at the termini of a brace (e.g., halo) is significant, paradoxical spinal motion may occur. **(b)** Spinal snaking is a manifestation of the paradoxical spinal motion phenomenon. It is depicted here in the case of a rigid external spinal splint. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

that occurs during the application of flexion, extension, or rotation stresses to the involved spinal segment and adjacent segments. Thus, option E is correct and option A, B, C, and D are incorrect statements. This motion occurs in two circumstances: (1) in cases of segmental spine instability and (2) in cases in which stabilization techniques (spinal implants or external splints) are used that limit motion between two nonadjacent vertebrae with at least two intervertebral discs located between the termini of the implant or splint (see ▶ Fig. 2.6). In segmental spine instability, paradoxical movement can occur at the index and adjacent levels. In the case of stabilization techniques, the suspension of vertebral body segments between rigidly immobilized segments allows segmental muscular attachments to cause segmental movement in a paradoxical manner (snaking). Snaking is a characteristic type of movement of spinal segments in response to external force applications. With such movement, the sum of the movements of individual spinal motion segments is greater than the overall spinal movement observed.[4] In some clinical circumstances, it can be objectively assessed.[5] In these cases, it can be quantified by measuring the overall movement between the rigidly immobilized rostral and caudal components. This is subtracted from the sum of the absolute values of each of the individual intervening segmental movements.[1] The paradoxical motion phenomenon may become significant with external spinal splinting or in cases in which an instrumented spine is not instrumented at every segmental level (e.g., only at the termini of the construct). In either case, movement of the suspended spinal segments can occur (between the extremes of the fixation).

▸▸ **Answer 7**

Correct answer is B

The law of conservation of momentum, or Newton's third law of motion, can be stated thus: interactions between objects result in no net change in momentum. When two objects interact via a collision, the first body exerts a force on the second. The overall momentum of the two bodies remains constant—i.e., any momentum lost by one body is gained by the other. In other words, for every action there is an equal (in magnitude) but opposite (in direction) reaction. Option B best describes Newton's third law of motion; thus, it is the correct answer. For example, when a force is applied to a vertebral body by the application of an axial load, the force applied by the vertebral body on its neighboring vertebral bodies is equal in magnitude

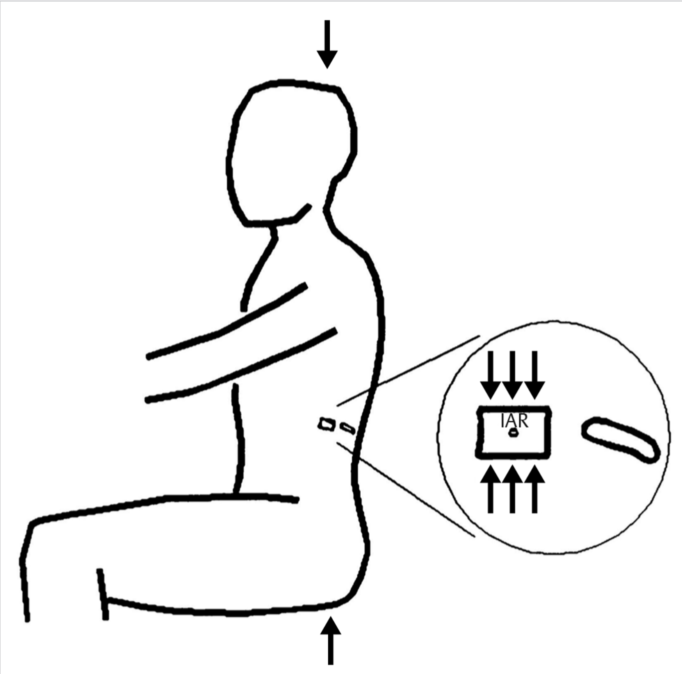

Fig. 2.7 Forces always occur in pairs. For every action, there is an equal but opposite reaction (Newton's third law). If an axial load is applied to a vertebral body, the forces impinging on the rostral and caudal portions of the vertebral body are equal. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

but opposite in direction to the applied force (see ▶ Fig. 2.7). This is a manifestation of Newton's third law of motion. This may subsequently result in deformation, or failure of integrity, of the vertebral body. Option A is incorrect as it represents Newton's first law of motion, the law of inertia, which may be stated as: if a body is subjected to no net external influence, it has a constant velocity, either zero or nonzero. As long as there is no force acting on an object, its speed and direction of motion do not change. Newton's second law of motion, the law of superimposition of forces, can be stated thus: the time rate of momentum of a body is equal in magnitude and direction to the vector sum of the forces acting upon it. In other words, an object responds to the summation of the forces applied to it. Therefore, options C and E are both incorrect. Option D describes momentum, which is the product of mass and velocity.

▸▸ Answer 8

Correct answer is D

A couple is a pair of forces applied to a structure that are of equal magnitude and opposite direction, having lines of action that are parallel but do not coincide. Thus, option D is the correct answer, and options C and E are incorrect. ▶ Fig. 2.1 illustrates a couple consisting of two forces, each of magnitude F, acting upon a structure and separated by a perpendicular distance D. The resultant force is zero ($F - F = 0$). Option B describes the effect of a couple on a structure; however, it is not the correct definition of this phenomenon. Option A describes coupling, which is the phenomenon by which a movement of the spine along or about an axis obligates another movement along or about another axis (of the Cartesian coordinate system), which is not to be confused with the physical principle of a couple.

▸▸ Answer 9

Correct answer is C

This pair of forces may result in deformation or failure of the vertebral body, resulting in a burst fracture; hence, option C is the correct answer and options A, B, D, and E are incorrect (see ▶ Fig. 2.8a). If the load is applied in a plane at some distance from the IAR, a bending moment is created (see ▶ Fig. 2.9). If this bending moment is matched with an equal (in magnitude) but opposite (in direction) reaction bending moment, this pair of forces may similarly result in deformation or failure of the vertebral body, resulting in a wedge compression fracture (see ▶ Fig. 2.8b). In this case, the ventral concentration of stress “facilitated” the ventral vertebral body failure. This type of deformation or failure may occur in any plane, depending on the point of application of the force vector (load). This is illustrated for a lateral bending component (see ▶ Fig. 2.10a) and for a combination ventral and lateral bending component (see ▶ Fig. 2.10b).

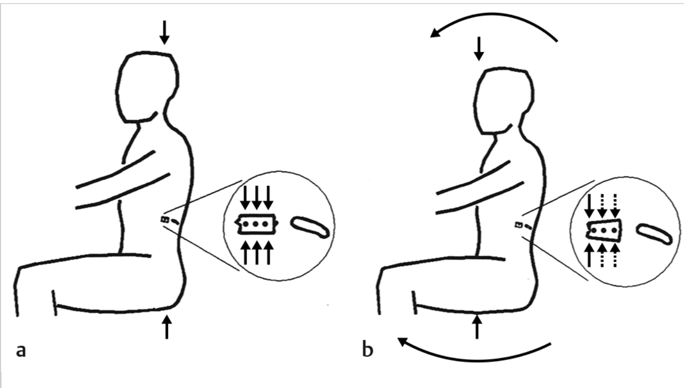

Fig. 2.8 **(a)** If a load is sufficient to result in vertebral body failure, the failure is of a burst fracture nature. **(b)** If, however, a load is applied in a plane ventral to the instantaneous axis of rotation (IAR), an asymmetric force pair and bending moment (*curved arrows*) will be applied to the IAR, resulting in a wedge compression fracture. Dots, IAR; *straight arrows*, loads; *curved arrows*, bending moments. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

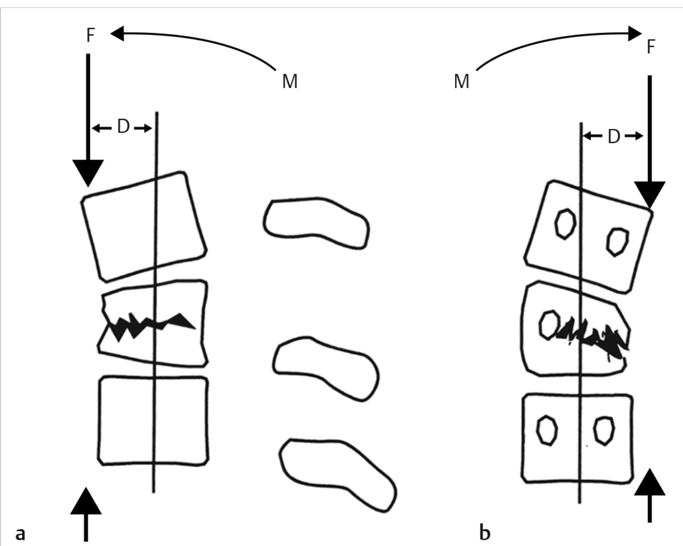

Fig. 2.9 The bending moment (*M*, depicted by a *curved arrow*) is the product of the force (*F*) and the length of the moment arm (*D*). The maximum bending moment is located at the center of the circle defined by the radius of the bending moment’s arc (i.e., the instantaneous axis of rotation). **(a)** Lateral view. **(b)** Anteroposterior view. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

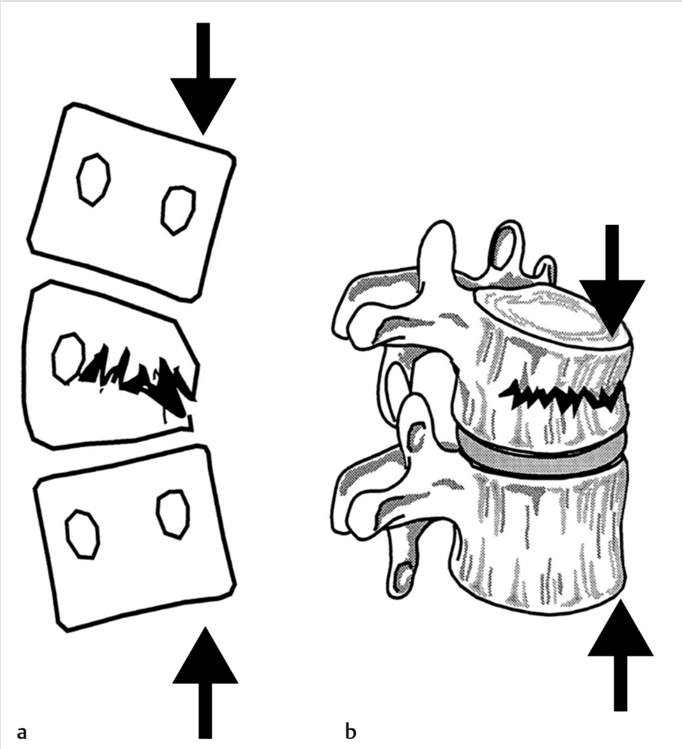

Fig. 2.10 The bending moment generated by the force pair may occur in any plane. **(a)** Lateral bending. **(b)** A combination of flexion and lateral bending. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

▸▸ Answer 10

Correct answer is A

Hooke's law states that for small displacements, the size of the deformation is proportional to the deforming force; hence, A is the correct answer, and options B, C, D, and E are incorrect. No solid is perfectly rigid. When several external forces act on a solid at rest and the resultant net force is zero, the solid will be deformed. This linear relationship pertains only to solids that are deformed within their elastic zone (see ▶ Fig. 2.11). Elastic deformation (in the elastic zone) occurs whenever a strain totally recovers following the removal of a stress. This law is important when one considers the forces applied to the spine by a spinal instrumentation construct, as well as the response of the construct to these forces. For larger displacements, however, the elastic zone is exceeded, and the elastic limit (or yield point) is reached. This is the point at which the force departs from the linear relationship between the extent of deformation and the deforming force (i.e., Hooke's law no longer applies).

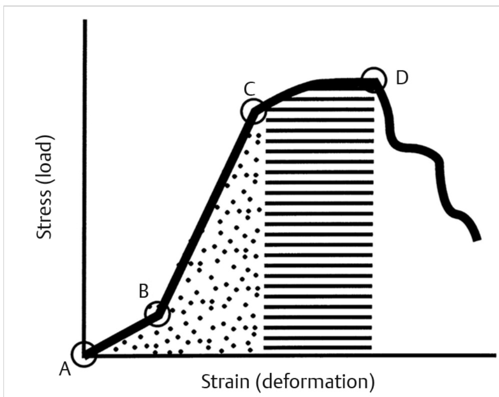

Fig. 2.11 A typical stress–strain curve for a biological tissue, such as a ligament. AB represents the neutral zone. BC represents the elastic zone. When the elastic limit (yield point (C) is reached, permanent deformation can occur (permanent set). CD represents the plastic zone where a permanent set occurs. Past D, failure occurs and the load diminishes. Striped area plus dotted area represent strength, whereas the dotted area represents resilience. (Source: Biomechanics of Spine Stabilization: Third Edition, © 2015 Thieme Medical Publishers, Inc.)

▸▸ **Answer 11**

Correct answer is E

This equation defines the resultant torque (bending moment) about any arbitrary point. In this case as illustrated in ▶ Fig. 2.1, translation will not occur, but rotation will occur if the couple is unopposed. Because x_1 and x_2 do not appear in the result, the torque of the couple is the same about all points in the plane of the forces forming the couple and is equal to the product of the magnitude of either force and the perpendicular distance between their lines of action. The concept of the couple is important, particularly regarding the complex forces applied by instrumentation constructs. Thus, option E is correct, and options A, B, C, and D are incorrect.

▸▸ **Answer 12**

Correct answer is E

When the elastic limit (yield point [C]) is reached, permanent deformation can occur (permanent set). CD represents the plastic zone where a permanent set occurs, so option E is correct and options A, B, C, and D are incorrect. Past point D, failure occurs, and the load diminishes. The striped area plus dotted area represent strength, whereas the dotted area represents resilience. AB represents the neutral zone. BC represents the elastic zone. For most materials, the elastic limit occurs close to the point where a permanent set is reached. The area under the stress–strain curve is proportional to the energy absorbed before failure (point of failure). This is a measure of strength. The removal of a stress recovers energy. The energy expended (area under the stress–strain curve up the yield point C) is a measure of an object's resilience. In vivo, most solids (e.g., bones) subjected to external forces are buffered from these forces by ligaments, tendons, and other soft tissues. Therefore, before the elastic zone is "reached," a zone of nonengagement (neutral zone) is passed. Within the neutral zone (AB in ▶ Fig. 2.2), the application of a small force results in relatively large displacement.

▸▸ **Answer 13**

Correct answer is B

The elastic modulus is defined by stress/strain, where the elastic modulus (modulus of elasticity) is a constant that is characteristic of a given material. The modulus of elasticity essentially should be thought of as a measure of the deformability of an object (i.e., stiffness). Stress is defined as the force applied to an object (load), whereas strain is defined as the response of the object to the force (deformation). Strain is the change in length or angle of a material subjected to a load. Strain may be either normal (linear) or shear (angular) in nature. Normal strain reflects tensile or compressive force–resisting abilities of a material; shear strain reflects angular deformation–resisting abilities of a material. Three types of elastic moduli exist: Young's modulus, a measure of the elastic properties of a body that is stretched or compressed; shear modulus, a measure of the shear deformation experienced by a body that is subjected to transverse forces of equal and opposite direction, applied at opposite faces of the body; and bulk modulus, the elastic deformation of a solid when it is squeezed.

▸▸ **Answer 14**

Correct answer is B

Stress (θ) applied to an implant is a function of two factors: bending moment (M) and section modulus (Z). The relationship is described by the equation $\theta = M / Z$. Therefore, option B is correct, and options B, C, D, and E are incorrect.

▸▸ **Answer 15**

Correct answer is C

Section modulus (Z) defines the ability of an object, such as a screw or rod, to resist bending.

$Z \propto \pi \times D^3/32$

It is proportional to the third power of the diameter of a rod or the third power of the inner diameter of a screw. Option C is correct, and options A, B, D, and E are incorrect.

▸▸ **Answer 16**

Correct answer is C

The moment of inertia essentially defines stiffness. Stiffness is proportional to the fourth power of the diameter of a rod or the fourth power of the inner diameter of a screw.

Stiffness $\propto \pi \times D^4/32$

Therefore, as the diameter of a rod is increased, the stiffness increases more rapidly than the strength, as strength is proportional to the diameter cubed, while stiffness is proportional to the diameter to the fourth power. Hence, larger diameter rods are more stiff than they are strong, when compared with smaller diameter rods.

▸▸ Answer 17

Correct answer is D

Newton's first law of motion, the law of inertia, can be stated as: if a body is subjected to no net external influence, it has a constant velocity, either zero or nonzero. As long as there is no force acting on an object, its speed and direction of motion do not change. Option A describes Hooke's law, option B describes Newton's second law of motion, and options C and E describe Newton's third law of motion and are therefore all incorrect answers.

▸▸ Answer 18

Correct answer is B

Coupling is defined as the phenomenon by which a movement of the spine along or about an axis obligates another movement along or about another axis (of the Cartesian coordinate system); thus, option B is the correct answer. In the cervical region, for example, lateral bending results in rotation of the spinous processes away from the concave side of the curvature (the direction of the bend). This is due, in part, to the orientation of the facet joints as well as to the presence of the uncovertebral joints. In the lumbar region, however, the coupling movements associated with the lateral bending are in the opposite direction, with the spinous processes rotating in the same direction as the concave side of the direction of the bend. The phenomenon of coupling also explains the association of the obligatory rotatory component associated with degenerative scoliosis of the lumbar spine. A describes the physical principle of a couple, which is different from the coupling effect; therefore, A is wrong. Placing a screw through a bone graft weakens the construct but is not associated with rotation or the coupling effect; option C is incorrect. A burst fracture may result when an axial load is applied to a vertebral body at the point of the IAR resulting in an equal (in magnitude) but opposite (in direction) reaction force; thus, option D is wrong. Using variable angle (nonfixed moment arm) screws in traumatic spine fractures may lead to construct failure, but this does not demonstrate the coupling effect. Therefore, E is incorrect.

▸▸ Answer 19

Correct answer is D

Momentum is the product of the mass and velocity of an object. Thus, option D is correct. Momentum, therefore, is defined in part by direction; it demonstrates its vector component in this manner. To appropriately appreciate the stresses withstood by the spine, the surgeon must understand the fundamental action–reaction phenomenon, and an appreciation of the concept of momentum is integral to this process. Option A describes the elastic modulus, option B is the definition of Hooke's law, option C defines stress, and option E describes section modulus; hence, options A, B, C, and E are incorrect.

▸▸ Answer 20

Correct answer is B

The area under the stress–strain curve is proportional to the energy absorbed before failure (point of failure) and this is a measure of strength; hence, option B is correct. The removal of a stress recovers energy. The energy expended (area under the stress–strain curve up the yield point) is a measure of an object's resilience; thus, option A is incorrect. Stress is defined as the force applied to an object (load), whereas strain is defined as the response of the object to the force (deformation); therefore, options C and D are incorrect. Option E is incorrect, as momentum is the product of the mass and velocity of an object.

Key Principles

- IAR is dynamic and depends on the different loads and forces applied.
- Hooke's law states that for small displacements, the size of the deformation is proportional to the deforming force.
- Stress = bending moment/section modulus.
- Elastic modulus = stress/strain.

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