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The Significance of Head Size in Maintaining Postural Equilibrium in the Donkey

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Abstract

The postural equilibrium of the donkey (*Equus asinus*) results from the complex interplay among body mass, body conformation, the spatial arrangement of individual body segments, skeletal configuration, muscular activity, and limb positioning relative to the supporting surface.

The fundamental distinction between statics and biostatics lies in the fact that statics examines and defines the principles governing stationary abiotic masses or structures, whose constituent elements do not actively participate in movement. By contrast, in the biostatic model of a living organism, the anatomical structures that provide static support also actively contribute to locomotion and, consequently, to biodynamics.

The head is not merely the terminal region of the body containing the sensory organs and the initial portions of the digestive and respiratory systems; it also represents a biomechanically significant mass. Its position relative to the trunk may alter both body-mass distribution and the location of the whole-body centre of mass.

However, the contribution of the head to postural balance in the donkey cannot be assessed using a single morphometric measurement. Head length alone provides no information about either the location of the head segment's centre of mass or that of the animal's whole-body centre of mass. Such an analysis requires, at a minimum, knowledge of the mass of the relevant body segment and the position of its centre of mass. A more precise model would additionally require data on the mass and centre-of-mass location of all major body segments.

Keywords: Donkey, Biostatics, Biodynamics, Biomechanics, Morphometry

Introduction

In general terms, the body of the donkey does not constitute an exception to the fundamental structural principles of mammals or to the basic principles of statics and dynamics. Statics examines the principles governing the equilibrium of an organism at rest, whereas dynamics addresses the laws governing bodies in motion.

When considering statics and attempting to compare the animal organism—in this case, that of the donkey—with an engineered structure, such as a bridge or another mechanical system, it must be borne in mind that an animal is not a machine. Its specific anatomical organization permits the application of certain principles of statics, although only under particular biological conditions (Nickel *et al*., 1968) [3].

The fundamental distinction between statics and biostatics lies in the fact that statics examines and defines the principles governing stationary abiotic masses or structures, whose constituent elements do not actively participate in movement. By contrast, in the biostatic model of a living organism, the anatomical components that provide static support also actively contribute to locomotion and, consequently, to biodynamics. This represents the fundamental difference between the statics of abiotic structures, such as buildings and machines, and the biostatics of living matter, specifically the animal body.

The mathematical principles governing the static equilibrium of the animal body are often not readily apparent, primarily because the same anatomical elements also participate in movement and displacement of the body. Since forward locomotion is of primary importance in determining the design of the locomotor system, its static properties are also fundamentally shaped by dynamic requirements. These requirements, in turn, contribute to species-specific differences and, within individual species, to breed-specific variation.

The postural equilibrium of the donkey (Equus asinus) results from a complex interaction among body mass, body conformation, the position of individual body segments, skeletal configuration, muscular activity, and limb placement relative to the supporting surface. Within this system, the head plays an important functional role; however, its influence cannot be properly understood when considered independently of the neck, thorax, vertebral column, pelvis, and limbs. The head constitutes the terminal, relatively mobile component of the cranial body segment, and its displacement alters the distribution of mass relative to the remainder of the body, thereby changing the position of the whole-body centre of mass.

The head is a relatively mobile body segment connected to the trunk through the neck, and its position can vary over a wide range without simultaneous displacement of the entire body. Consequently, changes in head position alter mass distribution within the cranial portion of the body and may affect both the position of the whole-body centre of mass and the moments of force acting on the neck, cranial portion of the trunk, and limbs.

The maintenance of postural equilibrium is an essential prerequisite for normal standing and locomotion in all animals, including the donkey. Postural equilibrium is one of the fundamental functional properties of the locomotor system, as it enables the animal to maintain a stable body position during standing, postural transitions, walking, movement across uneven terrain, changes in direction, and various forms of physical loading. Equilibrium does not result from the action of a single anatomical segment but from the continuous coordination of the position and activity of the head, neck, trunk, pelvis, and limbs. The head and neck occupy a particularly important position within this system because they constitute a mobile mass located cranial to the main body mass and continuously change position during standing and locomotion. In equids, the head and neck have been shown to play an important role in the craniocaudal and lateral control of equilibrium, with visual, vestibular, and proprioceptive information being integrated to maintain stability (Zsoldos and Licka, 2015).

The head is not merely the terminal part of the body containing the sensory organs and the initial portions of the digestive and respiratory systems; it also represents a biomechanically significant mass whose position relative to the trunk may alter both body-mass distribution and the location of the whole-body centre of mass. In equids, this function is particularly pronounced because of the relatively large combined mass of the head and neck and their position cranial to the trunk. A recent review of equine head and neck biomechanics reported that the head and neck together account for approximately 10% of total body mass and that their cantilevered position in front of the trunk generates a substantial moment of force around the cervicothoracic junction.

In a simplified representation, the head may be regarded as a mobile mass capable of influencing postural equilibrium. However, the term “counterweight” alone is insufficient to describe its function.

The head performs at least four biomechanical functions:

1. It constitutes a body-mass segment whose position influences the location of the whole-body centre of mass.
2. It functions as a lever, with gravitational force generating moments about the cervical joints.
3. It is connected to the cervical musculature and ligaments, which maintain its position through active and passive mechanisms.
4. It contains the vestibular and visual systems, both of which play important roles in postural control.

The role of the head in maintaining postural equilibrium must be considered within the context of the species-specific body conformation of the donkey. The donkey is not simply a small horse (Wissdorf *et al*., 2020; Urošević *et al*., 2025) [13, 6], nor can its biomechanical characteristics be regarded as entirely equivalent to those of the horse. Its morphology—including head shape, neck length and conformation, the relationship between height at the withers and height at the croup, body length, and the distribution of muscle mass—constitutes a distinct biostatic model. Morphometric studies have demonstrated considerable variability in body dimensions among different donkey populations, while more recent research has specifically highlighted the proportional relationships among the head, neck, and trunk.

However, the contribution of the head to postural equilibrium in the donkey cannot be assessed using a single morphometric measurement. Head length alone provides no information about either the position of the head segment’s centre of mass or that of the animal’s whole-body centre of mass. Such an analysis requires, at a minimum, knowledge of the mass of the relevant body segment and the location of its centre of mass. A more precise model would additionally require data on the mass and centre-of-mass location of all major body segments.

This is particularly important in the donkey because of its specific body conformation. Regional studies have shown that height at the croup frequently exceeds height at the withers in different donkey populations and that the proportions of individual body regions vary among populations and types. Ivanković *et al*. (2000) [1], for example, studied 270 donkeys from the coastal region of Croatia and distinguished three breeds: the Littoral Dinaric, North Adriatic, and Istrian donkeys. Significant differences were identified in height at the withers, chest circumference, cannon-bone circumference, and other morphometric traits.

Urošević *et al*. (2019) similarly emphasized the distinctive body conformation of the donkey. Within their biostatic model, they associated the positions of the pelvis and neck—and, indirectly, the position of the head—with the locations of the corresponding centres of gravity.

Postural equilibrium is particularly important in the donkey because of its distinctive body conformation. Unlike the morphology typical of many sport and working horses, the donkey is characterized by a specific relationship between croup height and withers height, a distinct neck carriage, a broad pelvis, and different proportional relationships among individual body regions. Urošević *et al*. (2019) associated this particular conformation with the donkey's biostatic model and its capacity for prolonged locomotion over uneven terrain. According to these authors, the positions of the croup and neck—and, consequently, that of the head—determine the location of the centre of gravity.

The fact that the positions of the neck and head influence the location of the centre of mass does not automatically imply that the head alone determines whole-body equilibrium. The position of the centre of mass results from the overall distribution of body mass. The head constitutes only one component of this system, whereas the neck provides a mobile connection between the head and trunk. Consequently, a change in head position alters the location of the head's mass and frequently induces a corresponding change in the position of the neck's mass.

The contribution of the head to whole-body equilibrium should therefore not be reduced to the simplistic assumption that forward displacement of the head automatically shifts the whole-body centre of mass cranially. Such an interpretation is biomechanically incomplete. The effect of head displacement depends on head mass, the distance between the head's centre of mass and the whole-body centre of mass, neck position, limb placement, trunk conformation, and the current phase of locomotion. The head and neck function as an interconnected mobile mass that influences the position and movement of the trunk through the cervical vertebrae, muscles, ligaments, and articulations. In equids, the influence of the neck on overall locomotion is sufficiently pronounced for it to be regarded as one of the principal mechanisms involved in the craniocaudal and lateral regulation of equilibrium.

Accordingly, the contribution of the head to postural equilibrium in the donkey should be considered at three interrelated levels:

a) Morphometric, concerning the size, shape, and proportional relationships of the head and neck;
b) Static, concerning the position of the centre of mass at rest; and
c) Dynamic, concerning changes in the positions of the head, neck, and centre of mass during locomotion.

Nevertheless, the contribution of the head to postural equilibrium in the donkey should not be attributed solely to its position as a discrete mass cranial to the trunk. From a biomechanical perspective, the head is the distal segment of the head–neck complex, and its position determines the moment of force transmitted through the cervical vertebral column and the cervicothoracic junction. At the same time, the head contains highly important sensory systems involved in the control of body posture. A change in head position therefore represents both a mechanical and a sensory alteration: head displacement changes body-mass distribution while also modifying the sensory information received by the nervous system regarding the position and movement of the body.

To understand this function, it is necessary to distinguish among the centre of mass of the head, the centre of mass of the head–neck complex, and the whole-body centre of mass. The whole-body centre of mass represents the resultant of the mass distribution across all body segments. If the body is represented in simplified form as a system of segments with different masses, the position of the whole-body centre of mass in the longitudinal plane may be expressed by the following equation:

$$\frac{xCM = \Sigma mixi}{\Sigma mi}$$

Where mi denotes the mass of an individual body segment and xi its position relative to a selected reference point. This relationship illustrates a fundamental biomechanical principle: any change in the position of an individual segment alters the location of the whole-body centre of mass. The magnitude of this effect increases with both the mass of the segment and its distance from the whole-body centre of mass.

In the case of the head, its distance from the main body mass is particularly important. Although the head accounts for only a proportion of total body mass, it is located at the distal end of a relatively mobile neck segment. Consequently, head displacement may generate a comparatively large moment of force. This effect cannot be considered independently of the neck, because most natural movements of the head are accompanied by simultaneous changes in neck position.

Direct investigations of this phenomenon in donkeys are considerably less extensive than those conducted in horses. A recent review of donkey biomechanics emphasized that the biomechanics of this species remain substantially less thoroughly investigated than those of the horse, particularly with regard to detailed kinematic and kinetic analyses (Parkes and Bukhari, 2026) [4]. Consequently, the function of the head in the donkey must be evaluated by integrating direct morphological data obtained from donkeys with general biomechanical principles and evidence derived from studies of horses. Nevertheless, findings obtained in horses should not be presented as characteristics directly established in donkeys.

This relationship is particularly relevant in the donkey because its head exhibits distinct species-specific morphological characteristics. Craniometric studies have demonstrated that the donkey's head is not merely a proportionally smaller version of the horse's head.

Urošević *et al*. (2022) described the body conformation of the donkey as a biostatic model that enables the generation and transmission of biokinetic energy. Their model proposes that body movement is achieved through the transfer of energy from the hindquarters, where it is generated, towards the cranial part of the body.

Accordingly, the head does not represent the primary source of energy for locomotion. Its role is principally associated with body-mass distribution, the maintenance of body posture, and the modulation of equilibrium during different phases of locomotion.

The donkey's head should therefore be regarded as an anatomically and biomechanically active body segment rather than as a passive terminal structure. Its mass, shape, and position influence static equilibrium, while its controlled movements during locomotion contribute to whole-body stabilization.

Location of the Centre of Mass

In warmblood horses standing squarely with body weight evenly distributed across all four limbs, the centre of mass is located at the intersection of the median plane and a vertical transverse plane positioned at 42.86% of the total body length, measured from the shoulder joint towards the ischial tuberosity. In coldblood horses, the centre of mass is located at 43.72% of the body length, measured from the cranial extremity of the sternum (Seiferle, 1962, as cited in Nickel *et al*., 1968 [3]).

In all quadrupeds standing with all four limbs in contact with the ground, the points of limb support delimit a rectangular base of support within which the vertical projection of the centre of mass is located when body weight is evenly distributed among the limbs. This projection lies cranial to the intersection of the diagonals connecting the contralateral forelimbs and hindlimbs. Its position cranial to the intersection of these diagonals indicates that the centre of mass is located within the cranial portion of the body.

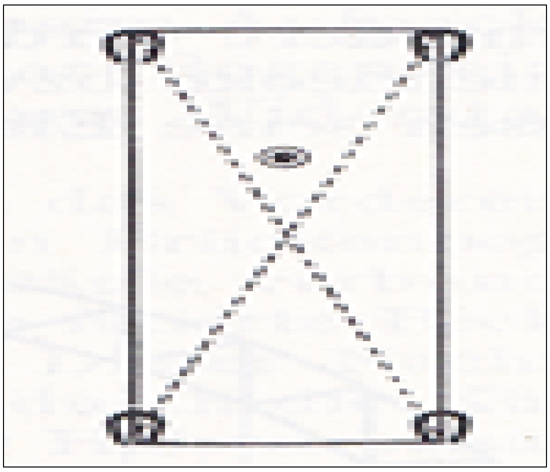

Fig 1: Vertical projection of the centre of mass during standing with body weight evenly distributed across all four limbs (Nickel *et al*., 1968) [3]

The body remains in equilibrium as long as the vertical projection of its centre of mass lies within the rectangular base of support defined by the hoof-ground contact areas.

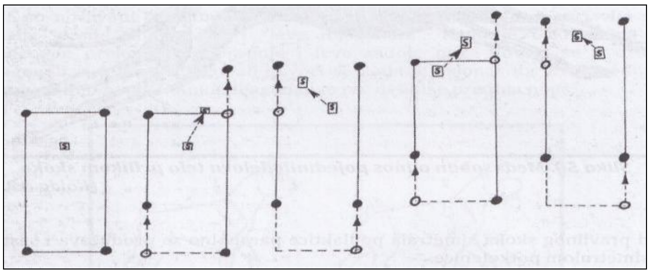

Fig 2: Displacement of the centre of mass in response to forelimb repositioning (Stockmann, 1985) [5]

During locomotion, four phases of limb action can be distinguished: (a) lifting, during which the limb is raised from the ground; (b) swing, which begins with flexion and is followed by extension of the joints, thereby advancing the limb cranially; (c) ground contact, during which body weight loads the joints and activates the extensor musculature; and (d) support and propulsion, during which the body advances while the limb establishes support at a new position.

During the support and limb-extension phase, the body is propelled forwards. During limb flexion and swing, the limb advances to achieve the required stride length. These phases alternate in a coordinated rhythm between a hindlimb and the diagonally opposite forelimb.

From a static perspective, it is particularly important that the forelimbs and hindlimbs do not bear equal proportions of body weight. Because the centre of mass is located within the cranial portion of the body, the forelimbs bear a greater load than the hindlimbs. In horses, approximately 55% of body weight is supported by the forelimbs and 45% by the hindlimbs.

To understand the structural organization of the back more clearly, it may be compared with the construction of a bridge. The limbs are often described as supports analogous to bridge piers positioned on opposite riverbanks, with body weight distributed between them. However, this analogy is not entirely accurate because it does not account for the positions and functions of other anatomical structures. These include the different regions of the vertebral column; the vertebrae and their spinous and transverse processes; the ribs, their curvature, and their spatial relationships; and the complete ventral support system, including the sternum and abdominal musculature.

The orientation of the lumbar vertebrae, particularly that of their spinous processes, is also highly important, including whether these processes are vertically aligned or slightly inclined.

Slijper (1946, as cited in Nickel *et al*., 1968 [3]) described the structural organization of the thorax using the analogy of an "arch bridge". The bridge deck—the surface used by pedestrians and vehicles—is connected to the arch by a series of supporting members.

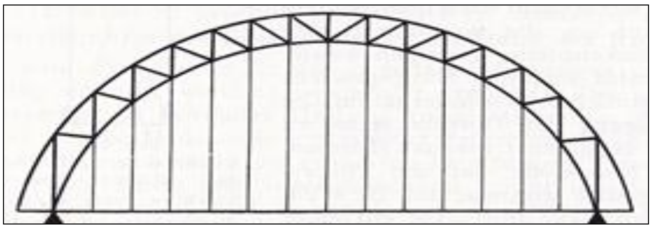

Fig 3: Bridge construction as an analogy for the structural organization of the back. The arch is connected to the horizontal deck by supporting members (Slijper, 1946, as cited in Nickel *et al*., 1968 [3])

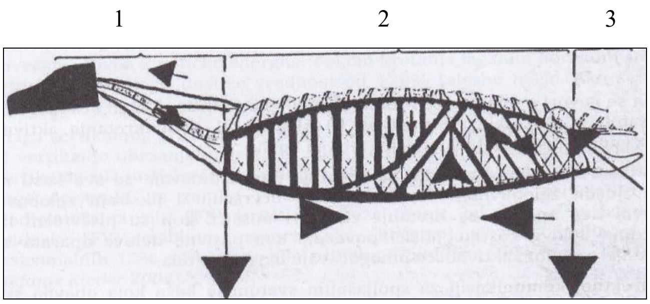

Fig 4: Body structure represented by analogy with bridge construction and the directions of force transmission: 1—cranial cantilever; 2—trunk bridge; 3—caudal cantilever (Stockmann, 1985) [5]

The available literature provides no reliable data on the precise location of the centre of mass in the donkey. Based on empirical observations and analyses of morphometric parameters in donkeys from several countries, Urošević *et al*. (2022) hypothesized that the centre of mass lies within a horizontal plane parallel to the supporting surface and passing through the cranial extremity of the sternum. According to these authors, the vertical level of the centre of mass is established during intrauterine development and remains unchanged throughout life. Only limited cranial, caudal, and lateral displacements within this plane are considered possible.

During standing, the centre of mass is presumed to be located at the intersection of the aforementioned horizontal plane and a vertical transverse plane passing between the ninth and tenth ribs.

The Biostatic Model of the Donkey Body as a Basis for Postural Equilibrium

To understand the distinctive body conformation of the donkey, it is first necessary to clarify the concept of the biostatic body model. The biostatic model provides the structural basis for biokinetic action, which, in turn, produces a biokinematic effect. This biokinematic effect results in cranial displacement of the body—that is, locomotion. Urošević *et al*. (2022) reported that the proportional relationships among individual body regions contribute to the donkey's considerable endurance and capacity for prolonged locomotion. The biostatic model therefore represents the anatomical basis, whereas its functional outcome is manifested as a biodynamic effect, namely movement.

Within this model, the caudal portion of the body plays an important role in generating the biokinetic energy required for locomotion. The pelvic and external hip musculature are particularly important, while the femur functions as a major lever in force transmission. Energy generated by the muscles of the hindquarters is transmitted through the hip joint, thigh, and hindlimb. The body is subsequently propelled forwards as the hindlimb exerts force against the supporting surface.

This model is relevant to the role of the head because equilibrium between the cranial and caudal portions of the body cannot be considered independently of energy generation and transmission. Cranial displacement of the centre of mass increases loading of the forequarters and reduces the relative load borne by the hindquarters. Conversely, caudal displacement produces the opposite effect.

When considering the distribution of body weight between the forequarters and hindquarters, Urošević *et al*. (2024) [7] reported that caudal displacement of the centre of mass may result in the hindquarters supporting approximately 60% of body weight and the forequarters approximately 40%. When the centre of mass shifts cranially, this relationship is reversed, with the forequarters supporting approximately 60% and the hindquarters approximately 40% of body weight.

These values should be interpreted as a description of a biomechanical model rather than as universal constants applicable to all donkeys. The actual distribution of loading depends on limb placement, body conformation, body mass, head and neck position, and the phase of locomotion.

The biostatic body model should be regarded as the anatomical foundation from which the biodynamic effect—locomotion—arises. The pelvis, hindquarter musculature, and femur, which acts as a lever in force transmission, are of particular importance within this model.

This approach is essential for understanding the role of the head because whole-body equilibrium is not maintained through the isolated activity of a single body region. The hindquarters generate a substantial proportion of the force required for locomotion, whereas the forequarters play an important role in accepting and supporting body weight. The head and neck can modify the distribution of this weight between these two functional regions.

If the donkey's body is represented in simplified form as comprising the head, neck, trunk, pelvis, and limbs, the following expression may be formulated:

$$xCM = \frac{mgl \cdot xgl + mvr \cdot xvr + mtr \cdot xtr + mkp \cdot xkp + mex \cdot xex}{M}$$

Where *mgl* is the mass of the head, *mvr* the mass of the neck, *mtr* the mass of the trunk, *mkp* the mass of the pelvis, *mex* the total mass of the limbs, *x* the position of the centre of mass of each respective segment, and *M* the total body mass of the animal.

This equation represents a simplified segmental model.

In an actual donkey, a larger number of body segments must be included. The reliability of the resulting estimate increases with the level of segmentation detail and the accuracy with which the mass and centre-of-mass location of each segment are determined.

The Biomechanical Significance of Head Mass

Let *mgl* denote the mass of the head, and assume that its centre of mass is displaced by a distance Δx. If all other body segments remain stationary, the resulting displacement of the whole-body centre of mass is:

$$\Delta xCM = \left(\frac{mgl}{M}\right) \cdot \Delta x$$

This expression is derived directly from the equation for the centre of mass and represents the mathematical consequence of mass distribution. For example, if the head accounted for 5% of the animal's total body mass and its centre of mass were displaced by 10 cm, the idealized displacement of the whole-body centre of mass would be: $\Delta xCM = 0.05 \times 10$ cm = 0.5 cm.

This value was not obtained experimentally in donkeys but is provided solely to illustrate the underlying principle. It would therefore be incorrect to state that a 10-cm displacement of the head automatically produces a 10-cm displacement of the whole-body centre of mass. The position of the whole-body centre of mass depends on the masses of all components of the system. Furthermore, the mechanical effect of the head depends not only on its contribution to the whole-body centre of mass but also on the moment of force it generates.

In a sample of 12 male donkeys, Urošević *et al*. (2026) determined head mass following slaughter and removal of the skin. Head mass ranged from a minimum of 4.420 kg to a maximum of 6.215 kg. These values represented between 5.71% and 10.19% of pre-slaughter live body mass.

Given that the total mass of the fresh hide accounted for 10.57–13.77% of pre-slaughter body mass, an approximate correction may be applied to the measured head mass to estimate the corresponding head mass in the live animal.

Centre of Mass and Centre of Gravity

In biomechanical analysis, a distinction must be made between the centre of mass and the centre of gravity, although their positions practically coincide in a body located within a uniform gravitational field.

The centre of mass is the point representing the resultant of the body's mass distribution. If the body consists of multiple segments, the longitudinal position of its centre of mass may be expressed using the general equation for determining the centre of mass of a composite system:

$$xCM = \frac{\Sigma(mi \cdot xi)}{\Sigma mi}$$

Where *mi* is the mass of an individual body segment and *xi* is the position of that segment's centre of mass relative to the reference point.

When the head is considered as an individual body segment, its contribution to the whole-body centre of mass depends on both its mass and its position. In a simplified model, the resulting change in the whole-body centre of mass may be expressed as:

$$\Delta xCM = \frac{mh}{M} \cdot \Delta xh$$

Where *mh* is the mass of the head, *M* is the total body mass, and *Δxh* is the change in the position of the head's centre of mass.

This expression indicates that a small positional change of a relatively light head will not produce a substantial displacement of the whole-body centre of mass when total body mass is large. However, because the head is located at the distal end of the mobile neck segment, its position may have a greater influence on moments of force than would be expected solely from its proportional contribution to total body mass.

In a realistic model, the head, neck, trunk, pelvis, and limbs must be considered simultaneously:

$$xCM = \frac{(mh \cdot xh + mv \cdot xv + mt \cdot xt + mp \cdot xp + me \cdot xe + \cdots)}{M}$$

Where *mh, mv, mt, mp* i *me* the masses of the head, neck, trunk, pelvis, and limbs, respectively.

This approach is considerably more precise than the simplified assertion that "the head displaces the centre of mass".

Morphological Basis of the Functional Significance of the Head

The influence of the head on postural equilibrium originates from its morphology. Head size and shape, facial length, cranial width, mandibular position, and the relationship between the head and neck determine both its mass and the location of its centre of mass.

In their study of the relationship between head length and pelvic length in relation to height at the withers in female donkeys from Romania, North Macedonia, and Türkiye, Urošević *et al*. (2015) [11] concluded that the head cannot be regarded as an isolated anatomical structure. Instead, it should be considered an integral body component whose dimensions exhibit specific relationships with the fundamental proportions of the body.

From a biomechanical perspective, the donkey's head represents the distal segment of the head–neck complex. Unlike the trunk, which constitutes a relatively large and centrally positioned body mass, the head is located at a distance from the main body mass and is connected to it by the mobile neck. Consequently, even a relatively small change in head position may alter the moment of force acting about the base of the neck.

The distance between the head's centre of mass and the base of the neck is particularly important. When a donkey raises its head, the head's centre of mass moves dorsally and, depending on neck position, may also shift either caudally or cranially relative to the trunk. When the animal lowers its head and extends its neck, the head's centre of mass generally moves ventrally and cranially. These positional changes alter the moment of force acting on the cervicothoracic junction and the trunk.

Fig 5: The head is relatively broad. The shadow clearly cast on the ground shows that head width exceeds the distance between the forelimbs (Photograph: M. Urošević)

Consequently, the head and neck function as a system of levers. The neck muscles generate not only the forces required to raise or lower the head but also those necessary to maintain a given head position against gravitational and inertial forces. During locomotion, additional forces associated with acceleration and deceleration arise; therefore, the biomechanical effect of the head is dynamic rather than static.

In horses, the head and neck together have been shown to constitute a substantial proportion of total body mass, while their position cranial to the trunk creates a considerable lever arm about the base of the neck. Although comparable quantitative data for donkeys are not available in the existing literature, the fundamental biomechanical principle may nevertheless be applied to this species. However, it must be recognized that the magnitude of this effect is not necessarily identical to that observed in horses.

The available literature contains few experimental biomechanical studies in donkeys that directly measure displacement of the whole-body centre of mass at different head positions. Consequently, conclusions regarding the influence of the head on postural equilibrium must be based on a combination of direct morphological data obtained from donkeys and well-established biomechanical principles derived from equids, particularly horses. Recent literature confirms that donkey biostatics, biomechanics, and biokinematics remain considerably less extensively investigated than those of horses.

The biomechanical function of the head depends primarily on its mass, shape, the location of its centre of mass, and the manner in which it is connected to the neck. Consequently, an understanding of postural equilibrium first requires knowledge of the morphology of the donkey's head.

A morphometric study of the skull of the domestic donkey, conducted on 16 skulls from adult males, included 40 different craniometric measurements. The mean total skull length was 443.07 ± 53.57 mm, while the maximum zygomatic width was 169.09 ± 17.64 mm. Based on the calculated indices, the authors concluded that donkey skull size was intermediate between that of the examined local horses and ponies. However, they also identified more pronounced differences in certain proportional relationships between the cranial and facial regions of the skull (Zhu *et al*., 2014).

Direct skull morphometry is also important for understanding the influence of the head on postural equilibrium. Merkies *et al*. (2020) [2] conducted a comparative study of horse and donkey skulls. The study included 14 horses and 16 donkeys, whose skulls were prepared and measured post-mortem. The authors analysed various cranial and nasal indices, as well as the surface area and position of the olfactory bulb. Compared with horses, donkeys exhibited a larger cranial profile, a smaller olfactory-bulb surface area, and a steeper olfactory-bulb angle.

These findings are biomechanically relevant because head length and mass determine its spatial relationship with the cervical axis and thereby influence the moment of force. Skull length alone, however, is insufficient to determine its biomechanical effect. This would require knowledge of the mass of the entire head and the precise location of its centre of mass. Such data were not included in the cited craniometric study; therefore, the moment of force generated by the head in a living donkey cannot be calculated directly from the reported mean skull length.

The distinction between morphometric data and biomechanical interpretation must be clearly maintained. The reported skull length represents a directly measured variable. By contrast, the conclusion that a particular skull length determines a specific location of the centre of mass constitutes a biomechanical interpretation requiring additional measurements. These two levels of evidence should not be conflated in scientific reporting.

The head must also be considered in relation to the neck. The neck forms a mobile segment between the head and trunk, and its length, mass, and conformation determine the extent to which changes in head position affect the whole-body centre of mass. Therefore, evaluating the head–neck complex is considerably more informative for assessing the biomechanical function of the head than treating the head as a completely isolated anatomical unit.

The Head and Neck as a Biomechanical Lever

The head does not act directly on the trunk. The neck lies between them and constitutes an anatomically and biomechanically mobile segment. The cervical vertebral column enables movement of the head and neck relative to the thoracic region of the vertebral column.

As previously noted, the influence of the head cannot be analysed independently of the neck. The neck provides a mechanical connection between the head and trunk while simultaneously constituting a mobile mass with its own centre of mass. Consequently, even the smallest change in head position almost invariably induces a corresponding change in neck position, thereby altering the location of the centre of mass of the entire head–neck complex.

From a functional perspective, the neck may be even more important than the head itself for understanding the influence of the head on postural equilibrium. The head is connected to the trunk through the cervical vertebral column, while the neck permits substantial changes in head position without requiring simultaneous displacement of the entire body.

Fig 6: The body remains in equilibrium despite substantial displacement of the head and neck (Photograph: M. Urošević)

For this reason, the head–neck system may be regarded as a mobile mass located in the cranial region of the body.

In the donkey, the position of the neck relative to the trunk is particularly important. In their analysis of the donkey's biostatic model, Urošević *et al.* (2022) identified four principal morphometric factors that determine the location of the centre of gravity: the position and height of the croup, the position of the neck, and the angle at which the neck is attached to the trunk.

The authors distinguished a more favourable model, characterized by a relatively low-set neck attached at an angle of up to approximately 30 degrees and a high croup, from a less favourable model characterized by a high-set neck attached at an angle exceeding 30 degrees and a lower croup.

Differences in neck angulation alter both the position of the neck's mass and the initial position of the head relative to the trunk. Consequently, an identical head movement may not produce the same biomechanical effect in two animals with different conformations.

The neck performs multiple functions. It enables the head to assume a wide range of positions, facilitates access to food and visual observation of the immediate and distant surroundings, and contributes to communication and behaviour. At the same time, it represents an important component of the locomotor system. Reviews of equine neck biomechanics indicate that neck movement is based on coordinated motions of the cervical vertebrae, while the effects of neck position are transmitted to the trunk and limbs through osseous, ligamentous, and muscular structures.

This relationship is particularly relevant in the donkey because of its distinctive body conformation. Comparative studies of the cervical vertebrae and nuchal ligament have demonstrated that donkeys exhibit a specific attachment pattern of the lamellar part of the nuchal ligament compared with horses and zebras. In donkeys, the ligament attaches along the sagittal crest of the cervical vertebrae without the characteristic digitations described in other equids.

This attachment pattern is highly important because it demonstrates that the mechanism providing passive support to the head and neck in the donkey cannot simply be inferred from descriptions of the horse. The morphology of the ligamentous system reflects the different mechanical demands acting on the neck.

The position of the head relative to the trunk depends on neck position. Urošević *et al*. (2024) [7] identified croup position and neck position—specifically, the angle at which the neck is attached to the trunk—as two important morphometric factors within their model.

In the White Baroque Donkey, the reported mean angle of neck attachment was 24.0 ± 5.4 degrees in males and 22.1 ± 5.2 degrees in females, with an approximate range of 15 to 30 degrees.

Fig 7: White Baroque Donkey (Austria) (Photograph: M. Urošević)

This finding is highly relevant to the role of the head because neck position determines the initial position of the head relative to the trunk.

If two donkeys have heads of equal mass but different angles of neck attachment, the horizontal positions of their heads' centres of mass relative to the trunk will not be identical.

This means that the same head mass may produce different biomechanical effects in two animals with different conformations.

The donkey's neck is not merely an anatomical support for the head; it is an active biomechanical element that determines how the head's mass is transmitted to the trunk and how head movements affect overall postural stability.

The fundamental mechanical principle explaining the biomechanical significance of the head is the moment of force:

$$M = F \cdot d$$

Where F is the force and d is the perpendicular distance between the force's line of action and the axis of rotation.

In the case of the head and neck, the force primarily results from the gravitational action on their mass. Depending on the level of analysis, the relevant axes may be considered to pass through individual cervical joints or through the cervicothoracic junction. The greater the horizontal distance between the head's centre of mass and the axis under consideration, the greater the moment that must be counterbalanced by ligamentous and muscular structures. This demonstrates that the head does not exert its effect solely through its mass; rather, it acts as a mass located at the end of a mobile lever.

As in other animals, the consumption of food in excess of metabolic requirements results in the accumulation of adipose tissue and an increase in body condition. The same process occurs in donkeys. Adipose tissue accumulates within the subcutaneous layer, forming deposits that effectively surround the body. Such a distribution of adipose tissue helps maintain postural equilibrium because it does not substantially disrupt the relative loading of individual body regions.

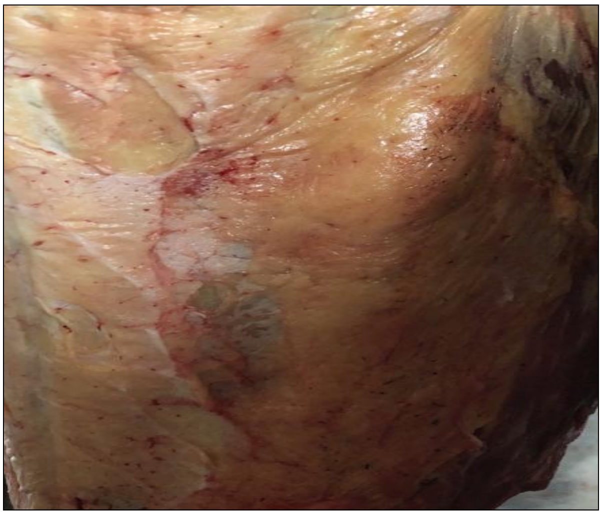

Fig 8: Adipose tissue is evenly distributed around the body within the subcutaneous compartment (Photograph: M. Urošević)

Once the capacity of the skin and subcutaneous tissues of the trunk to accommodate adipose tissue has been fully utilized, additional fat deposition begins in the neck. A sausage-shaped adipose deposit develops within the subcutaneous tissue along the dorsal aspect of the neck, beneath the mane. Adipose tissue subsequently accumulates along the entire dorsal length of the neck, forming a characteristic neck crest. This deposition increases neck mass and consequently increases the load borne by the cranial portion of the body.

Fig 9: Clearly visible sausage-shaped adipose deposit along the dorsal aspect of the neck

When a donkey extends its neck and moves its head cranially, the horizontal distance between the head's centre of mass and the trunk increases, thereby increasing the cranially directed moment of force. Conversely, when the head is brought closer to the trunk and its centre of mass shifts caudally, this moment decreases. However, the actual biomechanical effect also depends on the simultaneous displacement of the neck's mass. Therefore, a change in head position cannot be regarded as equivalent to a corresponding change in the position of the whole-body centre of mass.

Fig 10: The extended, robust neck acts as a lever, with the head—a substantial component of total body mass—positioned at its distal end (Photograph: M. Urošević)

Experimental studies and reviews in horses have clearly documented that neck movements affect the trunk and limbs. Zsoldos and Licka (2015) reported that the effects of neck position and movement are transmitted to the trunk and limbs through osseous, ligamentous, and muscular structures. The neck therefore constitutes an integral component of locomotor biomechanics rather than merely a passive connection between the head and trunk. The same authors also stated that elastic energy is stored within the passive structures of the neck during locomotion, including the ligaments, joint capsules, and fasciae, while additional activity of the cervical musculature is required to provide adequate stabilization.

These findings are relevant to understanding the underlying biomechanical principles in the donkey. However, they do not provide sufficient evidence to conclude that these processes occur identically in donkeys or that the same patterns of cervical muscle activity are present in this species.

Materials and Methods

To investigate the influence of the head on whole-body equilibrium, a morphometric study was conducted. The following parameters were measured in donkeys from Balkan countries: height at the withers, back height, croup height, body length, head length, neck length, chest width (frontal distance between the shoulder joints), thoracic width (measured behind the scapulae), height of the cranial extremity of the sternum, croup length, croup width, width between the ischial tuberosities, neck angle, and croup angle.All height measurements were obtained using a laser device mounted on a measuring stick, whereas lengths and chest width were measured using a measuring tape. Thoracic width was measured using a Lydtin measuring stick. Angular measurements were obtained using a technical protractor.

The donkeys were classified into three groups according to height at the withers: Group 1 (up to 105.0 cm), Group 2 (from 105.1 to 130.0 cm), and Group 3 (greater than 130.1 cm). Group 1 comprised 14 females and 13 males. Group 2 comprised 14 females and 14 males, whereas Group 3, which included the tallest animals, comprised only 10 males.

Results

The biostatic model of the donkey's body is highly specific and distinctive. When viewed from the front, rear, or above, the body has a trapezoidal shape.

Females in Group 1 (height at the withers up to 105.0 cm) had a mean chest width of 19.64 cm, ranging from 16.0 to 22.0 cm. Mean thoracic width was 26.99 cm, with values ranging from 20.1 to 30.5 cm. The range of absolute values was noticeably broader for thoracic width than for chest width. These measurements clearly demonstrate that body diameter increases in the caudal direction.

Mean croup width was 33.10 cm, ranging from 29.0 to 39.0 cm. A wide range of variation was also observed for this morphometric parameter. The body was widest in the croup region, followed by a pronounced narrowing of the pelvis. The mean width between the ischial tuberosities was 11.93 cm, with values ranging from 8.0 to 16.0 cm.

It is evident that the cranial region of the donkey's body is the narrowest and, consequently, the lightest. To maintain equilibrium and postural stability, the donkey has a large head supported by a robust, relatively short neck. According to general mechanical principles, a short lever can support a considerably greater load than a long lever.

Indices provide the most informative means of evaluating the proportional relationships among individual measurements. The neck index was calculated in relation to head length.

Table 1: Mean neck index values (%) according to sex and group

Group	*Females*	*Males*
1	72.02	65.82
2	67.40	66.50
3	-	62.74

Based on the neck index values, neck length was shorter than head length, irrespective of sex or height at the withers.

Table 2: Mean head index values (%) according to sex and group

Group	*Females*	*Males*
1	49.35	49.48
2	48.13	47.32
3	-	47.45

A comparison of head index values—that is, head length relative to height at the withers—shows that the relative differences in head length fall within a very narrow range of only 2%.

The location of the centre of mass is essential for maintaining postural equilibrium and depends primarily on the position and angle of neck attachment to the trunk, as well as croup height. Croup height exceeds height at the withers, a characteristic considered typical of animals used for work on hilly terrain. An elevated croup causes the centre of mass to shift caudally, thereby reducing the load on the hindquarters. As the hindquarters consequently support a smaller proportion of body weight, less energy is required to carry this portion of the body mass. A greater proportion of the energy generated can therefore be used as biokinetic energy. Its transmission towards the cranial portion of the body produces a biokinematic effect, namely locomotion.

The low-set position of the neck also contributes to displacement of the centre of mass, with the head consequently positioned as far cranially as possible. The measured neck angle represents the angle formed between the dorsal border of the neck and the horizontal plane.

Comparison of the mean neck-attachment and croup angles gives the impression of an image and its mirror reflection. The values of these two angles are approximately equal.

Table 3: Mean neck and croup angle values (degrees) according to group and sex

Group	*Neck*		*Croup*	
	Females	*Males*	*Females*	*Males*
1	23.57	19.61	20.0	16.46
2	22.43	26.07	21.57	20.43
3	-	22.10	-	22.70

Croup height has a significant influence on the location of the centre of mass and its cranial or caudal displacement. This relationship is inversely proportional to croup height. Thus, the higher the croup, the more cranially the centre of mass is displaced, and vice versa. In general, croup height in donkeys exceeds height at the withers.

Table 4: Relationship between mean height at the withers and mean croup height (cm) according to sex and group

Group	*Females*		*Males*	
	Height at the withers	*Croup height*	*Height at the withers*	*Croup height*
1	98.86	102.95	101.84	104.56
2	111.49	115.56	113.56	115.79
3	-	-	137.09	139.00

The data presented in the table clearly demonstrate that all donkeys, irrespective of sex or height at the withers, have a croup positioned higher than the withers. This represents the characteristic biostatic model of the donkey. In this manner, the hindquarters are relieved of supporting a proportion of body weight, while the load borne by the forequarters increases correspondingly. Consequently, the hindquarters expend less energy on supporting body mass and have a greater capacity to generate biokinetic energy. The cranial transmission of this energy produces the biokinematic effect referred to as locomotion.

Fig 11: Heavy head, low-set neck, slightly concave back, and high croup (Photograph: M. Urošević)

Body length exceeds height at the withers, resulting in a rectangular body format. In animals with this body conformation, the topline of the back is not level; the midpoint of the back lies below the highest point of the withers and, consequently, also below the highest point of the croup.

As previously emphasized, the centre of mass lies within a horizontal plane passing through the cranial extremity of the sternum. It is therefore particularly relevant to examine the sternal-point height index, which indicates the proportion of height at the withers represented by this measurement.

Table 5: Mean sternal-point height index values (%) according to group and sex

Group	*Females*	*Males*
1	66.80	66.99
2	65.75	68.12
3	-	63.47

When the entire sample is considered, irrespective of sex and height at the withers, the mean sternal-point height index values range from 63.47% to 68.12%, representing a difference of only 4.65%. By contrast, the difference between the tallest (140.6 cm) and shortest (90.5 cm) individuals was 35.63%. These findings suggest that, irrespective of body size or height at the with wielers, donkeys performing identical or highly similar tasks in different ecological niches require an approximately uniform biostatic model.

This indicates that the centre of mass is positioned at a height exceeding one-half of the height at the withers.

The principal descriptive statistics are presented in the following table.

Table 6: Descriptive statistics

Gender	*Group*		*N*	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Male	Grpup_1	Withers height	13	98.00	104.80	101.84	2.18
		Back height	13	88.50	102.80	98.39	3.85
		Croup height	13	100.20	107.10	104.56	2.18
		Body length	13	97.00	123.00	110.54	7.06
		Head length	13	48.00	55.00	50.38	2.10
		Neck length	13	28.00	38.00	33.15	3.60
		Forechest width	13	16.00	22.00	18.85	1.91
		Thoracic width	13	20.00	33.00	24.23	3.90
		Sternum apex height	13	60.00	74.00	68.23	4.25
		Pelvic length	13	32.00	41.00	35.62	2.36
		Pelvic width	13	29.00	43.00	34.00	3.42
		Sit bones width	13	11.00	18.00	13.77	2.35
		Neck angle	13	15.00	30.00	19.62	4.31
		Croup angle	13	10.00	25.00	16.46	4.31
		Valid N (listwise)	13				
	Group 2	Withers height	14	106.50	129.00	113.56	6.08
		Back height	14	102.10	121.00	110.88	5.48
		Croup height	14	110.00	129.20	115.79	6.01
		Body length	14	111.00	142.00	120.23	8.28
		Head length	14	48.00	61.00	53.71	3.47
		Neck length	14	28.00	49.00	35.71	5.36
		Forechest width	14	17.00	27.00	21.21	2.94
		Thoracic width	14	20.00	38.70	28.04	5.77
		Sternum apex height	14	71.00	91.00	77.07	5.86
		Pelvic length	14	35.00	43.00	37.50	2.14
		Pelvic width	14	33.00	41.00	36.36	2.34
		Sit bones width	14	12.00	17.00	14.36	1.60
		Neck angle	14	15.00	35.00	26.07	5.61
		Croup angle	14	10.00	35.00	20.43	5.92
		Valid N (listwise)	14				
	Group_3	Withers height	10	131.50	140.60	137.09	3.40
		Back height	10	126.00	139.50	133.10	4.26
		Croup height	10	133.00	144.10	139.90	4.05
		Body length	10	136.00	146.00	141.05	3.70
		Head length	10	58.00	71.00	65.00	4.37
		Neck length	10	38.00	47.00	40.70	2.91
		Forechest width	10	24.00	37.00	31.40	4.65
		Thoracic width	10	27.00	38.00	31.21	3.28
		Sternum apex height	10	76.00	93.00	86.96	4.82
		Pelvic length	10	42.00	50.00	46.90	2.88
		Pelvic width	10	43.00	52.00	49.10	3.48
		Sit bones width	10	16.00	23.00	18.85	1.94
		Neck angle	10	15.00	30.00	22.10	5.26
		Croup angle	10	15.00	35.00	22.70	6.11
		Valid N (listwise)	10				
Female	Grpup_1	Withers height	14	90.50	104.70	98.86	3.78
		Back height	14	91.20	101.90	96.65	3.18
		Croup height	14	94.70	110.00	102.95	4.20
		Body length	14	101.00	124.00	113.49	7.00
		Head length	14	43.00	54.00	48.79	2.78
		Neck length	14	30.00	40.00	35.07	3.15
		Forechest width	14	16.00	22.00	19.64	2.02
		Thoracic width	14	20.10	36.50	26.99	4.98
		Sternum apex height	14	62.00	70.00	66.07	2.73
		Pelvic length	14	31.00	39.00	34.50	2.28
		Pelvic width	14	29.00	39.00	33.07	2.59
		Sit bones width	14	8.00	16.00	11.93	2.53
		Neck angle	14	10.00	35.00	23.57	6.91
		Croup angle	14	10.00	25.00	20.00	4.80
		Valid N (listwise)	14				
	Group 2	Withers height	14	105.50	125.70	111.49	5.67
		Back height	14	96.00	121.50	107.39	6.60
		Croup height	14	106.70	128.80	115.56	6.05
		Body length	14	110.00	135.00	122.41	8.37
		Head length	14	48.00	58.00	53.64	3.10
		Neck length	14	30.00	49.00	36.14	5.76
		Forechest width	14	17.00	25.00	21.29	2.58

		Thoracic width	14	23.80	40.80	30.44	4.05
		Sternum apex height	14	65.00	79.00	73.21	3.68
		Pelvic length	14	35.00	44.00	38.57	2.68
		Pelvic width	14	34.00	42.00	38.71	2.46
		Sit bones width	14	13.00	18.00	15.29	1.59
		Neck angle	14	15.00	30.00	24.14	4.31
		Croup angle	14	15.00	35.00	23.71	6.57
		Valid N (listwise)	14				

Across all groups and both sexes, none of the morphometric parameters had a standard deviation exceeding 10. This finding indicates that the body conformation of the donkeys included in the present study was relatively homogeneous. The lowest variability was recorded for chest width. For this morphometric parameter, standard deviation values ranged from 1.91 in Group 1 males to 4.65 in Group 3 males.

The widest range of standard deviation values was observed for body length. The minimum value was 3.70 in Group 3 males, while the maximum was 8.37 in Group 2 females.

Head and neck dimensions, which are highly important factors in whole-body equilibrium, also exhibited low standard deviation values. For head length, the minimum standard deviation was 2.10 in Group 1 males, while the maximum was 4.37 in Group 3 males. For neck length, the minimum standard deviation was 2.91 in Group 3 males, while the maximum was 5.76 in Group 2 females.

Considering that the donkey is a domestic animal that has been subjected to relatively limited artificial selection, particularly for conformation traits, these values may be regarded as a notable example of successful natural selection.

The biostatic model of the donkey's body is highly specific and distinctive. When viewed from the front, rear, or above, the body has a trapezoidal shape. In the overall sample (n = 64), mean chest width was 21.98 cm, mean thoracic width was 26.10 cm, mean croup width was 37.61 cm, and mean width between the ischial tuberosities was 14.61 cm. A graphical representation of the donkey's body shape, excluding the head and neck and viewed from above, is presented in the following diagram.

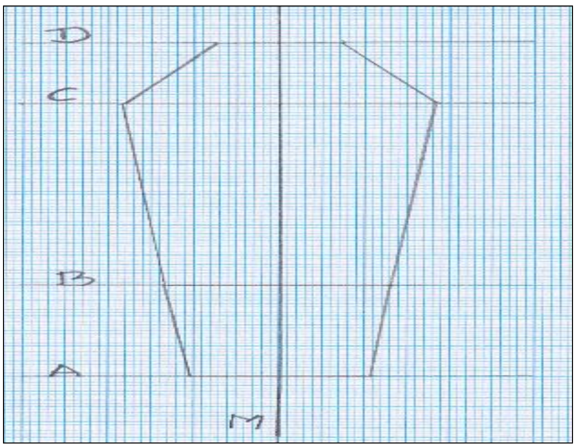

Fig 12: Trapezoidal shape of the donkey's body in dorsal view, excluding the neck and head (Original illustration: M. Urošević). Legend: M—vertical median plane of the donkey's body; A—chest width; B—thoracic width; C—croup width; D—width between the ischial tuberosities

Conclusion

The donkey's head is a biomechanically significant body segment whose functional role extends far beyond its anatomical function of housing the sensory organs and the initial portions of the digestive and respiratory systems. As a relatively distant mass positioned cranial to the main body mass, the head, together with the neck, influences the location of the whole-body centre of mass and the moments of force acting about the cervicothoracic junction. Cranial, caudal, dorsal, or ventral displacement of the head alters the conditions under which the donkey maintains postural equilibrium, although the resulting effect depends on the simultaneous positions of the trunk, pelvis, and limbs.

It must be recognized that the donkey possesses a specific biostatic body model. Its croup is positioned higher than the withers, while pelvic orientation, the distinctive conformation of the hindlimbs, neck position, and the relationship of the head to the trunk collectively form an interconnected biostatic system. Urošević *et al.* developed this concept in studies published in 2019, 2022, and 2024.

Lowering the head towards the ground displaces the mass of the head–neck complex cranially and ventrally, whereas raising and retracting the head reduces the cranial moment and increases the caudal moment. These changes resulting from head and neck repositioning are compensated for by corresponding adjustments in the positions of the trunk and limbs. The importance of these relationships becomes even greater during load carrying, as the additional mass alters the location of the centre of mass of the entire system.

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