BORN TO WALK

Myofascial Efficiency and the Body in Movement

JAMES EARLS

Coauthor of *Fascial Release for Structural Balance*

FOREWORD BY THOMAS MYERS

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Foreword

It is a great pleasure to introduce readers to incisive ideas. James Earls is a critical thinker; when he applies his brain to a question like gait, the result is worth the effort to read and understand. This is true of *Born to Walk,* where human plantigrade posture and bipedal gait are given the full circle of his imaginative but no-nonsense treatment.

It is also a great personal pleasure, of course, to see the ideas of *Anatomy Trains,* first published in 1997, taken up and expanded into this bold new work. The application of the Anatomy Trains myofascial meridian lines in the dynamics of gait (rather than the compensatory patterns of posture, as it was originally put into practice) is an exciting new direction for the Anatomy Trains model.

We live in a dynamic era, poised atop two crucial turning points. One is the dynamic between the "old" anatomy—the reductive anatomy of the musculoskeletal system as we have understood it since Vesalius—and the more "holistic" vision implied by the Anatomy Trains model, fractal mathematics, systems theory, and a host of recent research on myofascial force transmission. The attempt in *Anatomy Trains,* and certainly the attempt here in this book, is to bend these two ends and make them meet.

"Particulate" anatomy—"this muscle goes from origin to insertion and thus performs this set of actions"—is clearly inadequate to explain what is going on during daily coordinated movement. On the other hand, the holistic premise—"everything is connected to everything else"—while true, leaves the questioner in a vacuous world where everything is possible. So how do we strategize? How do we decide where to go and what to do next and when we are finished?

The "parts" view and the holistic view must be married, and *Born to Walk* gets them at least affianced, if not all the way down the aisle. The physiotherapist will find much in this book to get his or her teeth into in terms of specifics and isolating tests for determining the site of malfunction, and the model is built on classic gait theory. The holistic practitioner will likewise find much to fill in the "everything's connected" trope with practical advice as to how to see, assess, and work with the whole person in motion.

The second turning point we are at, in this early part of the twenty-first century, is the increasing amount of somatic alienation and "sensori-motor amnesia" that we see in our texting young, our sedentary workers, and our debilitated elderly. Clearly, we need an integrated approach to "KQ" (Kinesthetic Intelligence, Movement Literacy) for our urbanized populace—a group that includes more than just city dwellers. I live in a town of six hundred souls in a lovely, rural part of the United States, but I still live an entirely "urbanized" life.

Aside from educating current and upcoming generations, we need to educate our professional brethren. The emerging field of "Spatial Medicine"—changing the body position or movement to change the person—will bring together orthopedic doctors, physiatrists, physiotherapists, osteopaths, chiropractors, personal trainers, Pilates and yoga teachers, bodyworkers and manual therapists of all stripes, and somatic educators like Alexander Technique teachers and Feldenkrais practitioners. In my experience, each of us has something to learn from all these approaches, each of which have something to offer the whole field, and each separate school of thought has much to learn from the other parts of the field.

Over the next generation, all these tender "shoots" will eventually bind into a strong and comprehensive theory of anthropological development, biomechanics, physical education, rehabilitation, and skill maintenance that will promote a functional body, no matter what one's individual circumstances are. As we move behind the tail of the Industrial Revolution and enter the mouth of the Electronic Era, this effort—to reach out, understand the value in other approaches, and to apply the results toward a grand theory—will take on greater and greater significance, as our children's connection with nature is curtailed and "virtual reality" becomes less virtual and more palpably real.

Born to Walk is a vital step along this path, the bringing together of the holistic and the classical view to understand the uniqueness of human gait in terms that are both practical and visionary, scientific and poetic, grounded and uplifting.

I enjoy the book you have in your hands, and I expect that you will too.

Thomas Myers
Clarks Cove, Maine
November 11, 2013

Introduction

Man is a model of the world.
—Leonardo da Vinci c. 1480

"Vitruvian Man," Leonardo da Vinci's instantly recognizable sketch of the proportions of man, is a powerful symbol that demonstrates the relationship between architecture and anatomy and has been a source of inspiration for artists and architects over the centuries (fig. 0.1). Yet it is also one of the clearest expressions of the reasons for our limitations in the study of anatomy over the last 3,700 years.

Figure 0.1. "Vitruvian Man" by Leonardo da Vinci, c. 1487.
Along with the accompanying text, it outlines the ideal human proportions and is sometimes referred to as the "Canon of Proportions" or "Proportions of Man."

We can't really blame Leonardo, however. The symbol was drawn at a time of human history when we knew no better. In fact, the sketch was probably the epitome of the contemporary thinking of the Renaissance. Da Vinci made concrete and visible the ideal relationships between human anatomy, the divine, and the universe, as described by Vitruvius.

Writing sometime around 20 BCE, Vitruvius was instructed by the emperor Augustus to redesign, reformulate, and reinvigorate the beleaguered Roman Empire. Vitruvius wanted to establish a new format for the design of towns and buildings, and Augustus wanted a "Corpus," literally a body of work that would encapsulate the reformation of the "body of the empire." Vitruvius's *De architectura libri decum* (Ten books on architecture) was the outcome. It was the first work to outline the role and aspiration of an architect, and it sought to define many of the necessary elements of architecture.

Vitruvius's fundamental tenet was that "the power of nature has acted as architect" in biology: universal laws of nature had brought about human anatomy, and so, within our body's design, we had a map of the macrocosm. The body was literally a *minor mundus,* a "mini world," and, thereby, a reflection of the universe. The implication was that the architect should apply the wisdom and proportions of the body's design to architectural design and creation: "No temple can be put together coherently without symmetry and proportions unless it conforms exactly to the principle relating to the members of a well-shaped man."

Figure 0.2. The statue of the spear-bearer by the Greek sculptor Polykleitos was originally created 450–400 BCE. It was referenced by many as an example of the ideal proportions of a man, including Galen, the hugely influential physician, six hundred years later, as well as by Vitruvius and, eventually, by da Vinci.

In drawing Vitruvian Man, da Vinci wanted to demonstrate his mastery of anatomy and his understanding of the divine, as well as his mechanical and architectural prowess. By encapsulating the human form within the circle and the square, he was demonstrating the divine and the earthly relationships of the body, the slight upward shift of the circle allowing the navel to become the geometric center as well as a physiological one. The problem is that he operated with the tools of the time: a set square and a compass. In doing so, Leonardo set a foundation stone of anatomical misunderstanding within the modern world, by setting out a geometrical perfection of anatomy that would be associated with the tools and methods of fifteenth-century construction.

The use of the human body as the model for architecture lasted for many centuries. The body was used to inspire architecture, and the inverse was applied as well, with architecture and the idea of bricks and mortar being used to build an understanding of anatomy. Herein lies the problem with our traditional analysis of anatomy.

We naturally understand the progression of setting one brick on top of another—most of us have been doing that experiment since we first sat up and began playing with blocks. It is one of our first learned constants of the world: the relationship between gravity, inertia, and balance. Just as we used the body to inform architecture, over the centuries we have used our understanding of architecture to inform our experiments with the body. We have walked a two-way street with one discipline informing the other.

Many anatomy books still use the block-type image to portray the human form. It is still a popular depiction within my own profession, structural integration, employed by its originator, Dr. Ida Rolf. The language of engineering has entered the anatomical lexicon with the use of levers, cantilevers, force couples, supports, and attachments. And so we are naturally seduced into seeing anatomy with the same eye that we use to look at the manmade world around us.

While da Vinci may have been the source of this misinformed view of the body, he was also the inspiration for a new way of thinking about the body. Late fifteenth-century thinking was dominated by the Bible and by Aristotelian teachings of the natural and religious worlds. The writings of Galen were almost universally accepted without question. Da Vinci was among the first to start breaking this tradition, separating dogma from observable, demonstrable fact. By separating these two elements within Vitruvian Man—the circle (the divine) and the square (the earthly)—he was anticipating the changes that would develop through the world in the following few centuries.

Immersing himself in anatomy and, in the process, revolutionizing its portrayal, da Vinci began to see that many anatomical features were not as had been described by Galen 1,200 years previously. Many of these mistakes were still being taught in universities and, rather than trust the "wisdom" of his contemporary anatomists, da Vinci undertook many of his own dissections, the sketches of which are now kept as part of the Royal Collection in London.

Da Vinci inspired many scientists to follow in his footsteps. The Belgian anatomist Vesalius (1514–64) took further liberties in challenging the Galenic tradition, and in his dissections at the University of Padua acted as both dissector and lecturer *(ostensor cum sector).* This went against the established practice of having a dissector *(sector),* demonstrator *(ostensor),* and a lecturer *(lector).* The latter's job was primarily to simply regurgitate the writings of Galen as the dissector cut and the demonstrator pointed to the relevant parts, whether or not they matched the descriptions being given.

Shortly after Vesalius's time in Padua, the English physician William Harvey (1578–1657) also wished to branch out, preferring to believe his observation rather than received wisdom. His persistence—some might say obstinance—resulted in the medical breakthrough of the understanding of the circulation of blood.

Thus scientists in the sixteenth and seventeenth centuries began to challenge the orthodoxy, casting a new light of inspection onto many of the ancient scripts that had hitherto been accepted without question. Everything was up for scrutiny, and thinkers like René Descartes and Francis Bacon gave the world the tools it needed for critical analysis, leading us into the Age of Enlightenment (from around 1650).

The explosion in scientific undertakings in the mid- and late seventeenth century included Huygens (mathematics and astronomy), Boyle (chemistry), Wren (architecture and physics), Leibniz (mathematics), Hevelius (astronomy), Leeuwenhoek (microscopy), and two of our heroes for this book—Isaac Newton (1642–1727) and Robert Hooke (1635–1703).

Newton's work on gravity and motion is familiar to many of us, but the work of Robert Hooke, Newton's contemporary, is less so, even though it covered many more areas and foresaw much that could not be fully understood at that time. To appreciate the benefits of our bipedal gait and our design as nature intended, we must pay homage to the work of both men. We must understand Newton's principles of motion and our interactions with gravity and the ground, but they fully make sense only if we also invoke the elastics of Hooke.

Despite publishing one of the earliest—if not the earliest—close-up images of a flea (fig. 0.3), Robert Hooke only worked with nonorganic elastics and springs, and so we cannot be fully informed by his work. But we will see that the interaction between the principles of gravity and elasticity established by these two men, who at times were adversaries, gives a new understanding on how our bodies function. Hooke has been honored by having the symbol representing the elastic sections in the body named after him (see chapter 1).

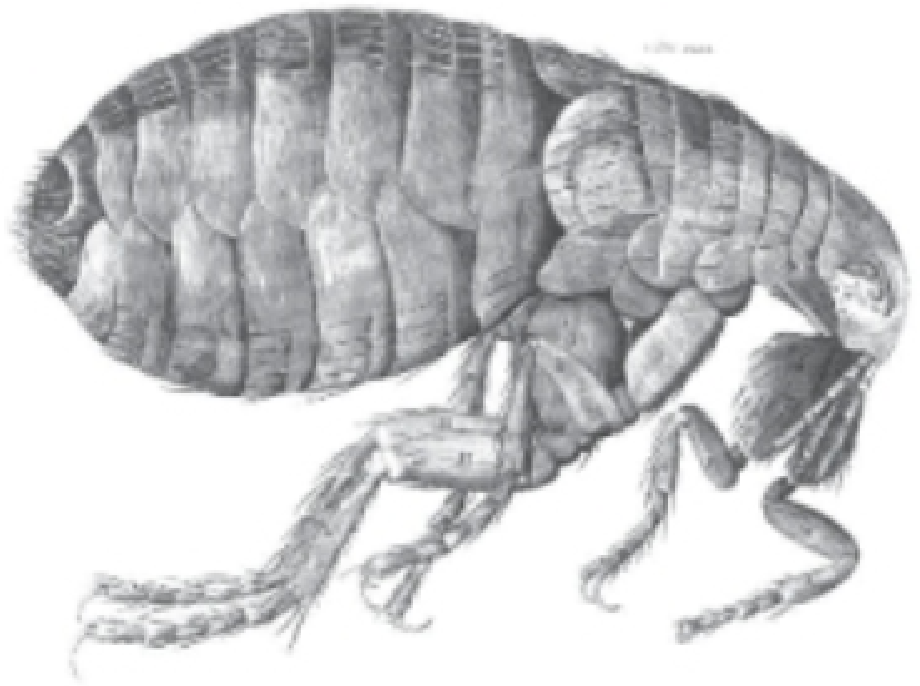


Figure 0.3. Published in 1665, this image, from Micrographica by Robert Hooke, helped to popularize science. It was perhaps the first "popular science" title and included many other firsts, such as the use of the word cell, as well as early work on fossils, predating Darwin by some two hundred years.

It is through the combination of gravity and our tissue's response to our momentum that we can gain practically free energy. By using the body's movement to stretch elastic tissues, we recruit the captured energy and then recoil the kinetic energy (the energy of motion) to help create a return movement. It is to this mechanism that much of this book is dedicated; it gives us the gift of relaxed and graceful movement that we recognize through its ease and the flow through and incorporation of the whole body.

Up until the twentieth century, scientists took a predominately Cartesian approach to the body, concentrating on "parts" and maintaining the image of the body working as an architectural machine. This concept of the body was not really challenged until 1948, when the sculptor Kenneth Snelson produced a series of structures that unintentionally imitated the interaction between the bones and the myofascia of the body (see fig. 0.4). Snelson, then studying with the philosopher and architect Buckminster Fuller, used tensioned wires to support solid, compressional struts. Fuller went on to develop the ideas and geometry of what he came to term "tensegrity" structures, using them as models for elements of the natural world from the atom to humanity to the universe (an interesting echo of the earlier natural philosophers' desire to show the geometry of the microcosm matching the macrocosm).

Figure 0.4. Using tensioned wire and metal struts, self-supporting structures can be created. The integrity of the structure requires the interplay between the compression and tension elements. As Snelson points out, however, while the breaking of one element in a simple structure can lead to its collapse, challenging one area in more complex constructions will be less catastrophic (for more, see his website, http://kennethsnelson.net/faq). We will see this again as we look further at the body and how it can adapt to dysfunction in any area.

In Snelson's and Fuller's world, to understand the system, we have to fully comprehend the connecting elements. That universal connecting ingredient in our bodies is the fascial tissue, a previously under appreciated element of our makeup, yet a wondrous multifaceted material that both binds and separates organs, and stabilizes and facilitates the mobility within us.

Now, in the twenty-first century, the fascial system seems to be attracting the attention it deserves. This has been due to the groundwork established by many pioneers, including Ida Rolf (1896–1979) and her many students, Thomas Myers in particular, with his development of the comprehensive fascial map, Anatomy Trains. By combining the principles of the physics of Newton and Hooke; the systems of Fuller and Snelson; the anatomy of Thomas Myers; and the functional movement of other pioneers, such as Jacquelin Perry, Gary Gray, and David Tiberio, I hope that this text can bring a united understanding of one of humanity's defining characteristics, bipedal gait.

This book aims to show that the body is "designed" along the lines of a different model from that extrapolated from the world of masons so beautifully encapsulated by da Vinci in his Vitruvian Man. I hope to show a model that will prove to be far more informative and satisfying, one that allows the whole body to adapt and cooperate with the movement of walking, and one that shows how we utilize the energy-saving mechanisms inherent within our anatomy. And, if I can borrow the words from Newton's reply to Hooke's accusation of plagiarism, if there is anything worthwhile in this book, "if I have seen any further," then it is not through my own efforts, but simply because I have had the opportunity to "stand on the shoulders of ye Giants."

And so I must thank all of those who have given of their time to me: Trefor Campbell, without whom this journey would not have gotten started on this path; Don Thompson and Kathy Green, without whom the journey would be less fun and certainly much longer; Thomas Myers, Art Riggs, and David Tiberio, who made the path smoother and less winding through their guidance; my loving partner, Liza Cawthorn, without whom the journey would have been long and lonely, her kind supportive guidance and affection made this trek smoother and I would certainly not have reached the end without it (plus a huge thanks from every reader for the many hours of editing, the book would not have made sense without it!); and, of course, my parents, without both of them the first steps would never have been taken. Thanks to my long suffering support team at Lotus Publishing, Simon Chiu for his expert technical support, Amanda for her patience as I often read the map upside down or back to front and we had to double back a few times, Wendy for her clarity in putting the map on the page, and, of course Jon who let us go on this saunter together.

Solvitur ambulando, St. Jerome was fond of saying. To solve a problem, walk around.
—Gregory McNamee

People usually consider walking on water or in thin air a miracle. But I think the real miracle is not to walk either on water or in thin air, but to walk on earth. Every day we are engaged in a miracle which we don't even recognize: a blue sky, white clouds, green leaves, the black, curious eyes of a child—our own two eyes. All is a miracle.
—Thich Nhat Hanh

ing System”

Four legs good, two legs bad.
—George Orwell, *Animal Farm*

The body divides itself into two units: passenger and locomotor.… The passenger unit is responsible only for its on postural integrity.
—Jacquelin Perry, *Gait Analysis*

Walking while nursing an injured arm in a cast throws off your balance and distorts your geometry of the walking body, creating various tensions and asymmetries that in themselves create further pain. My broken arm ached and it made the rest of my body ache, too.
—Geoffrey Nicholson, *The Lost Art of Walking*

Walking on two legs requires a tremendous act of balance and is often described as “controlled falling”—if we do not successfully put one foot in front of the other, we’ll fall to the ground. For our four-legged friends, walking must be so much easier, as they always have at least two points of contact with the ground at any one time. For us, walking requires the ability to have just one foot on the ground and to maintain some form of equilibrium within our tall, straight, and very unstable structures.

We walk to move around, to take our head and hands to other places, to achieve needs and desires. This apparently simple action requires a brain and nervous system; it demands internal planning and an ability to predict actions and reactions. It makes use of the many other cooperative senses that we have developed over millions of years. For elegant and efficient walking, each of our “systems”—especially those of sight, balance, and sensation—must be communicating in harmony. This requires the coordination abilities of the brain and nervous system.

One of the inherent problems in the study of anatomy is that we organize anatomy by these “systems.” In breaking the organization of the body down into similar tissue types, we tend to focus our attention on just one system at a time. Ideally, we should talk about the “walking system” throughout this book, but, alas, that would be a much larger tome, and it would require knowledge beyond my capabilities. Therefore, I must limit myself to analyzing the body's neuro-myo-fascial-skeletal-vestibular system, and my main focus will be on the myofascial elements and their cooperation.

Homo sapiens developed as generalists; we can adapt to many different situations, weaknesses, and disabilities. A glance at the people on any city street will quickly demonstrate various strategies for what we call "walking." There are many factors—neurological, visceral, emotional, cultural, and structural—that can alter how we walk. The number of possible interactions within those factors would be too large to list and would possibly require consultation with just as many professionals to unravel. It is for that reason that I will concentrate on developing a model of "normal," nonpathological gait.

This book presents a version of what can happen when the whole body is allowed to move together. I hesitate to call it "normal," but it is a pattern that is inherent within most of us—within the lines and grooves, contours and forms of our inherited anatomy. It is the relaxed, repetitive walking that allows our brains to be otherwise occupied, facilitating our gift to "walk and talk," to philosophize, to compose, to fall in love, to meander through any number of human preoccupations. It is a gift eulogized by many—from the peripatetic philosophers to Wordsworth and Dickens—and a facility brought about through what Bernstein (the founder of motor-control theory) referred to as "level B functioning." Walking, according to Bernstein, uses synergy among many different muscles, coordinated without any input from the brain, relying on self-monitoring by the proprioceptive system (Latash 2012). In our exploration of the myofascial system, we will see how the mechanoreceptors are located within the fascial tissue and seem to form a computation system that allows walking to be a subconscious activity.

Your body is built for walking.
—Gary Yanker

I believe the whole body walks. That might sound like a ridiculously obvious thing to say, but many schools of thought exist in the modeling of gait that narrow their gaze to analyzing just one aspect of human motion. One of the most widely accepted theories splits the body into "locomotor" and "passenger" sections—the pelvis and lower limbs versus the head, arms, and trunk (Perry and Burnfield 2010). Another school of thought, put forward by Gracovetsky, suggests that we only require the deep spinal muscles to move (2008). The alternate contraction of the multifidi, he argues, gives us the rotational movement we need to propel ourselves in any direction.

While there is certainly a truth in each of these theories, they are—for me—quite incomplete. We use the whole body to walk: the pelvis and legs are assisted by the trunk and the arms. The whole body helps balance and movement by increasing and decreasing the forces moving through the soft tissue. The whole body also works to lessen the amount of distortion that reaches the head. We need to keep our eyes relatively level, and we certainly do not want the force of impact rattling our brains at each heel strike, so we require the trunk and shoulder girdles to constantly adapt to keep the head steady.

The three elements of the walking system I will focus on most will be the fascial, muscular, and skeletal elements. These combine to form a wonderful, symbiotic map of the forces that travel through the body. The shapes and contours of the bones and their joints create pathways, like dry riverbeds, which, come the flood, will direct the water along preferred paths. The bones and joints assist the body through a controlled pattern of shock absorption, with the folding of joints taking place along predictable lines that send the force of impact into the semifluid streams of myofascial tissue.

The first port of call for our journey through the walking body will be the sequence of events in the bones and joints, in chapter 2. Understanding the natural inclination of the bones and the way they move on impact will allow us to interpret the role of the soft tissues, which—provided the other systems are properly in place—react to the forces by keeping us upright and still moving forward.

The myofascial tissues are not always consciously directed (as most anatomy books say they are) but are often reactive in behavior. For example, the tibialis anterior can be actively contracted to create plantarflexion and inversion, but its role in walking is to react to the body's interaction with the ground to prevent, control, or slow down eversion and dorsiflexion. Its contraction in walking is a response to the lengthening of tissues around it as the foot is planted on the ground—it's a totally unconscious reaction (see fig. 1.1). This reaction is controlled by the proprioceptors in the fascia, and thereby we see the role of the nervous system in this already increasingly complicated story.

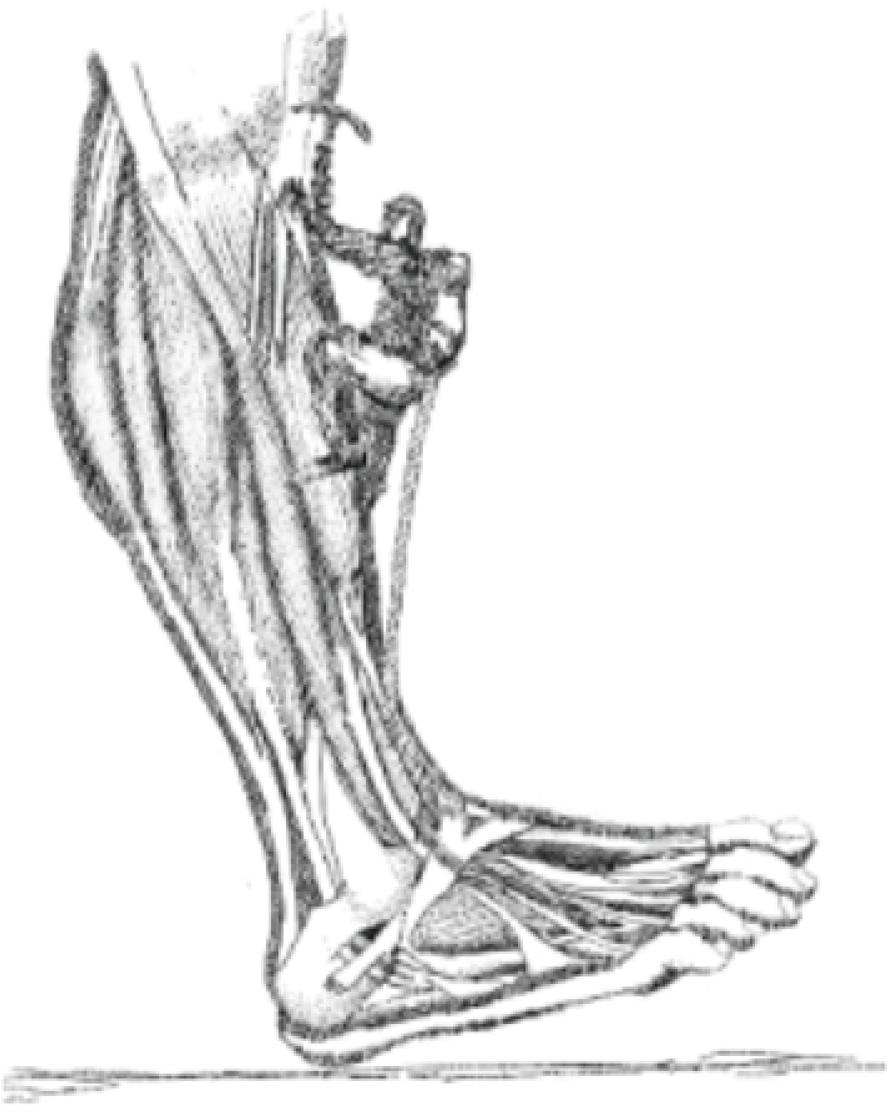


Figure 1.1. The impact of the foot on the ground will send forces into the soft tissue along the channels determined by the joints. These changes are felt by the proprioceptors, and an automatic response is created by the neuromuscular system to control the movement. Through the gait cycle, the tibialis anterior (and all of the other muscle units) will be constantly adjusting its tension in response to the surrounding events, reacting first to the eversion of the calcaneus and then to the ankle plantarflexion (see chapter 3, "Superficial Front and Superficial Back Lines", for further breakdown).

In the morning a man walks with his whole body; in the evening, only with his legs.
—Ralph Waldo Emerson

The body's many proprioceptors are constantly sensing changes in tension and relative position and communicating this information to the appropriate muscles. The wonderful work of Huijing has shown us that the mechanical force at a tendon is not communicated only along the muscle itself but is also dispersed into the surrounding fascia and can therefore be felt by the proprioceptors imbedded within neighboring muscles (1999a and 1999b, see fig. 1.2). In this way, a change at one end of a muscle can lead to its many neighbors being stimulated, depending on the pattern of movement.

This means that the fascial tissue of tibialis anterior, for example, can perceive mechanical information not only from its neighbors—extensors hallucis and digitorum longus, fibularis longus and brevis—but also from tibialis posterior or any of the other muscles of the leg. It is constantly receiving three-dimensional information of what is happening in the tissue around it and responding to those changes, creating a four-dimensional assessment and reaction to mechanical forces (time being the fourth dimension). The role of the proprioceptors is covered more fully in chapter 6.

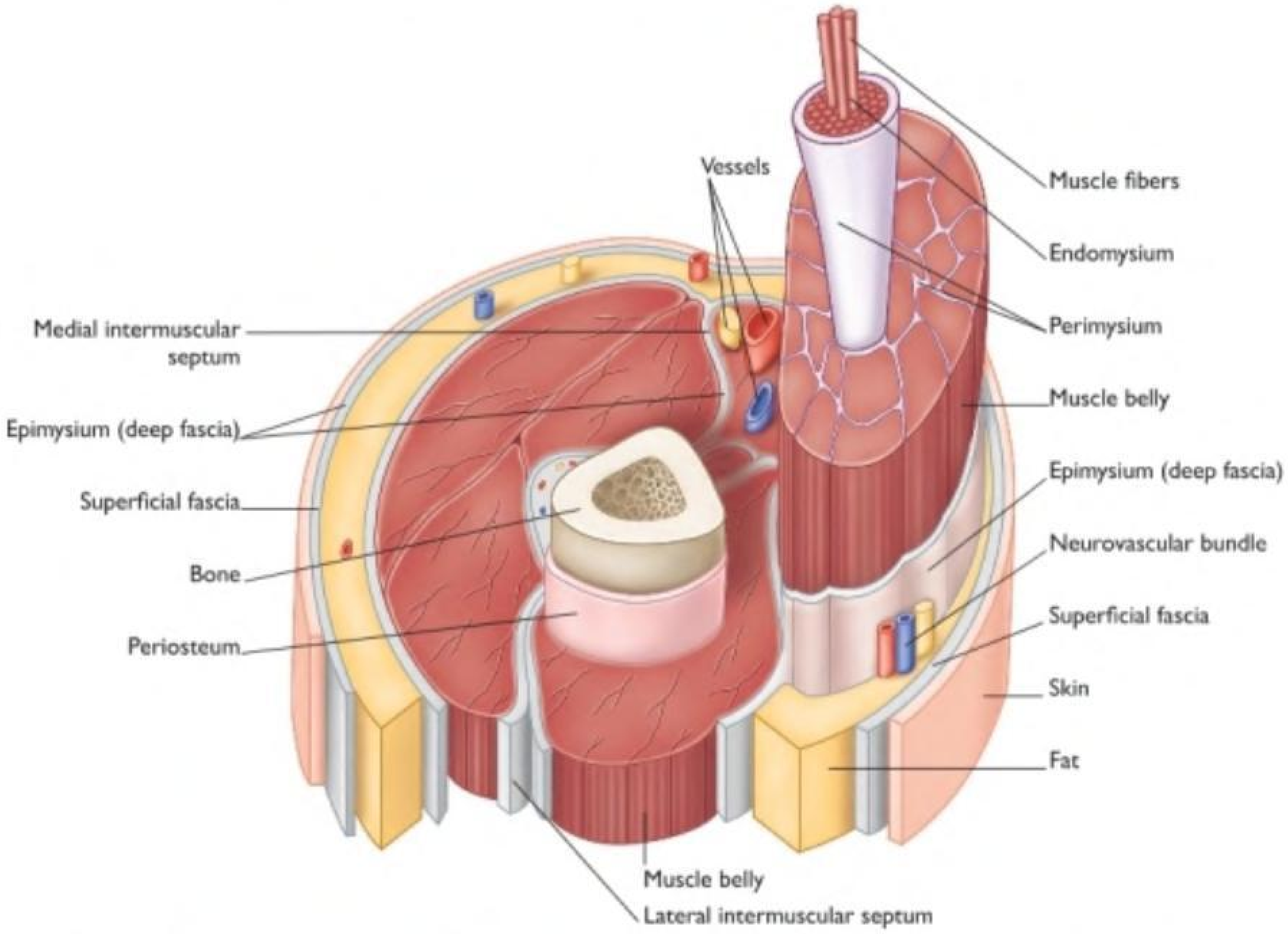


Figure 1.2. Pull or lengthen the distal attachment of any muscle, and that force will go out into the surrounding fascia to be sensed by the proprioceptors. Other myofascial elements can then make appropriate responses to the force in keeping with whatever mechanical information they are receiving from their own four-dimensional environment.

It is that extra dimension of time that makes description of walking so complex, as we have to visualize and analyze our adaptations in the three planes (sagittal, frontal, and transverse) as the body moves through time, changing positions. I hope the analysis put forward in this book helps ease some of that burden.

OUR RELATIONSHIP WITH GRAVITY

Walking is posture in motion.
—Mary Bond, "The New Rules of Posture"

During my training in structural integration, I would often hear the saying (almost a mantra for some people) that we have to live and align ourselves with gravity, that gravity is both our friend and our enemy. This always made perfect sense to me in terms of static postural assessment, in which we can see the impact of imbalanced segments and the strains that gravity causes.

I believe the statement fully comes to life, however, when we see the body working as the "walking system" of the bones, joint alignment, and the neuromyofascial continuum. Our eyes are naturally drawn to efficient, flowing, graceful movement: the joints moving freely in their designated ranges and directions; the myofascia receiving the appropriate information, both from the somatic nervous system and from sensing the mechanics of the surrounding tissue. When all of these happen together, we perceive a harmonious relationship, both of the body within itself and of the body with gravity.

It looks easy because it is. Nothing in the body is being taken advantage of; there is no overextension; and there is movement everywhere. The whole body is working as one to achieve its goal. When this happens, we achieve efficient movement. And strangely, it is the inherent instability of our two-legged stance that produces this efficiency.

UNDERGROUND FORCES AT WORK

"Ground Reaction Force" may sound like a subterranean terrorist group, but it is actually a vitally important aspect of understanding what is happening during gait. Unfortunately, it is also probably one of the most confused aspects. This is the stage where many readers may be tempted to skip a few pages, as they feel the imminence of the "science bit"—but please hold true just for a few pages. It will serve you very well, not just for the rest of this book, but also in the understanding of any human movement.

Figure 1.3. Ground reaction force is more complex than a simple rebounding of energy, as would be predicted from a simple understanding of Newton's third law.

One of the problems with explaining ground reaction force is that it begins to invoke physics, and everyone loves to quote Newton's third law: "To every action there is an equal and opposite reaction." What this means is that when my foot hits the ground, the ground pushes right back at me with the same force, but in the opposite direction, and this helps keep me upright. Sometimes in movement classes, instructors encourage their students, "push into the ground and feel it push you back up." Unfortunately, this is a bit of an oversimplification.

Let us begin with the difference between walking on asphalt and walking on sand—we all know the extra work that is needed when sauntering across a beach. Taking the example of the asphalt first: when we push into it, the surface will deform slightly (not enough for us to notice it with ordinary human senses, but it does happen), and it will return to its original state as we push off from it.

When we walk on the beach, however, the force with which we push into the surface is used to displace the many thousands of grains of sand. The grains are not connected to one another, and so the beach does not have an elastic capability to regain its original form. When we heel strike in sand, most of the force is therefore dispersed and gets lost in the movement of the grains.

If we looked very closely at the sand, we could see that the movement of each grain will depend on its shape and the angle from which it is pushed. Because the grains of sand aren't bonded together, these changes are similar to hitting balls on a pool table. Once the force stops acting on the grains (or balls), they come to rest where they are, rather than return to their starting position.

Much of the energy inherent in the foot strike was used up by the displacement of the sand. Now imagine that the grains of sand were joined to one another by strong elastic bands. Each of those movements by the sand would be reversible, just like a trampoline, which is temporarily displaced but, due to its elasticity, returns to its original shape—and thereby returns the energy used to displace it by pushing the person who jumped on it into the air.

Until now we have considered the body as a reasonably solid object—when imagining a body jumping on a trampoline, the discussion focused only on stretching of the trampoline alone. But actually the body is also being "displaced"—stretched and moved—when it lands on the trampoline. The skeleton is analogous to the grains of sand, with each bone being moved in a different way through the interaction of gravity, momentum, and ground reaction force. In the human body, however, the bones are held together by elastic tissue, the myofascia, which absorbs the forces coming from each of these three dynamics. This, as you will see, is vital to our understanding of walking, and we must be able to visualize the interactions between the forward momentum of the gait, the downward force of gravity, and the supporting ground reaction forces.

The interaction between the foot and the ground is simple when one is standing still. But in walking, the ground reaction force is not perpendicular to gravity. It is this angle of impact that invokes the folding of the joints throughout the body, and, as we will see as we progress through the book, it is the controlled adjustment of the joints that "loads" the tissue to assist recovery and recoil. (The springs of the trampoline can be seen as an analogy. They are stretched—"loaded" with recoil power—when someone jumps on the trampoline.)

Figure 1.4. When one is standing quietly, gravity is pulling the center of gravity down, and this is being "met" by the ground reaction force pushing straight up.

A full exploration of ground reaction force gets much more complicated than we need for our overall picture of the economy and cooperation of walking (and it can sprout lots of scary-looking equations), but a simple version of how ground reaction force works will help us see what happens in the body when it interacts with the ground.

Figure 1.5. As the heel hits the floor, the force "pushes" back at the heel in the opposite direction; this is what decelerates movement of the calcaneus.

ENERGY CONSERVATION

So much of my travelling is done on foot, that if I cherished betting propensities, I should probably be found registered in sporting newspapers under some such title as the Elastic Novice, challenging all eleven stone mankind to competition.
—Charles Dickens, "Shy Neighbourhoods"

EVOLUTION AND ECONOMY

Walking upright is one of the factors that sets us apart from our nonhuman primate cousins and is considered to be one of the main forces behind our evolution into our current *Homo sapiens* selves. Creating a stable, resilient form with the least calorie usage has been a driving force within nature. Different animals have used different strategies to achieve this equilibrium; evolution is a multifactorial process that cannot be tied down to any one dynamic. Compare the lumbering gait of a rhinoceros to the waddle of the penguin and to the flow of Grace Kelly's dancing. All are the products of millions of years of evolution on different branches of the tree of life. The rhino has sacrificed grace for strength and a tough hide, allowing it to win most fights in the search for calories. The penguin may look comical on land but is bullet-like in the water, where it meets both its prey and its predators.

Homo sapiens gave up strength and speed and instead aimed for efficiency and generalization. Minimizing our calorie expenditure in the search for food—and maximizing the many strategies we can use to catch, find, or grow it—led to what and where we are now. We made use of many factors inherent in our bodies, especially the potential that was unleashed when we became capable of standing, walking, and running on two legs.

As a nation we are dedicated to keeping physically fit—and parking as close to the stadium as possible.
—Bill Vaughan

Our brain requires sixteen times more energy than the chemical-to-mechanical-energy-transformers we call "muscles." With 20 percent to 25 percent of our daily resources being diverted to the brain, it makes sense that we take measures to ensure the supply of food to this important organ. The current strategy of the average American is to keep bodily exertion to a minimum—for instance, by walking only 350 intermittent yards per day (McCredie 2007). But this is not a good strategy. Strolling short distances, starting and stopping, takes more muscular effort than sustained walking at a regular pace.

Efficiency is of vital importance for our survival: if we can minimize our calorie output and maximize our intake, we are more likely to survive. Any variation in our anatomy that will enhance that ratio in our favor will be more likely to be passed onto the next generation—it will be favorably selected. As Cochran and Harpending demonstrate in their entertaining text *The 10,000 Year Explosion*, genetic changes can spread throughout a population surprisingly quickly, with a natural tendency to favor the more effective or positive influences (2010). For example, they argue that the protein dystrophin may have influenced our ratio of muscle to brains and that the changes in this ratio were selected in a relatively short period of time. Around a hundred thousand years ago, we clearly had more muscle and less brain, but in a relatively short space of time, the amount of energy invested in our brains compared to that invested in our muscles became more balanced. (Though, as we will see in chapter 4, Neanderthals actually had larger brains than we do today.)

Our nonhuman primate cousins have evolved a variety of movement strategies, including the knuckle walking of gorillas and chimpanzees and the four-limbed tree walking of orangutans. Nearly all of them, however, have to use a variation of the bent hip/bent knee posture for movement. This is not due to limitations in length of the hip or knee flexors but rather is caused by a limitation in the lumbar spine, which does not allow for enough extension to bring the pelvis in line with the knees and the feet (see fig. 1.6).

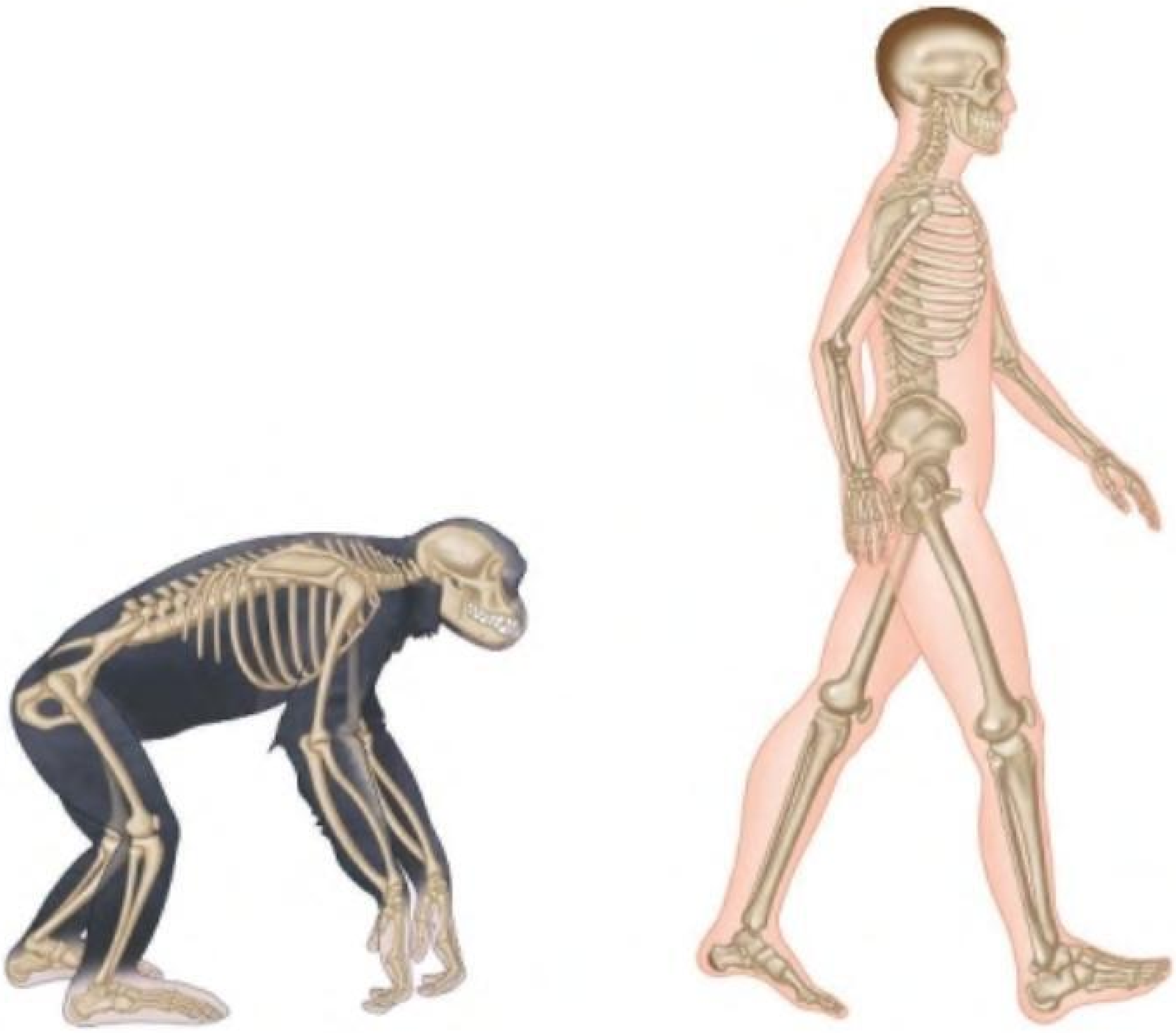


Figure 1.6. It is the lumbar-extension capability of the human that allows the secondary curves of the spine to adapt to an upright stance. This brings the head, thorax, pelvis, knees, and feet into a more vertical alignment.

One effect of the upright stance has been to greatly reduce the size of the spinal erectors, which are in almost constant use in the forward-leaning posture of the other hominids (see fig. 1.7). The cost, however, has been to place the lumbars in a more unstable position, prone to spondylolisthesis and scoliosis (Lovejoy, in Vleeming et al 2007). At first, this may not have been a costly adaptation, as hunter-gatherers may not have lived long enough for these degenerative issues to develop as often as they do today.

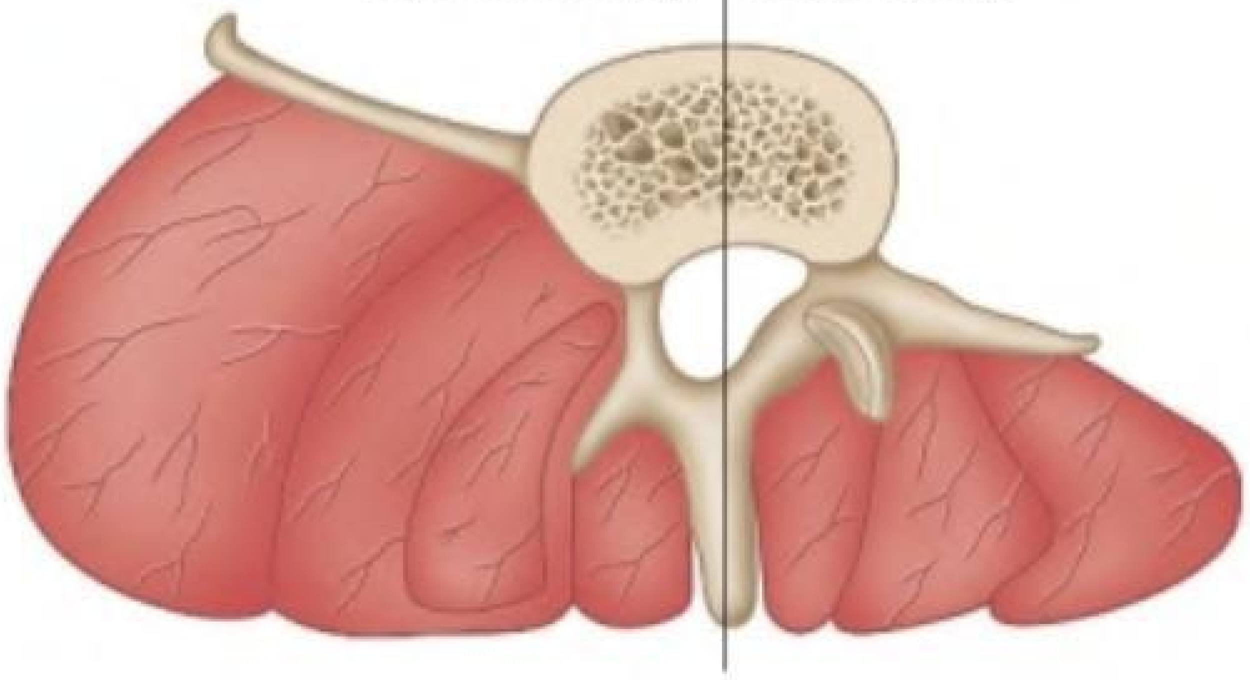
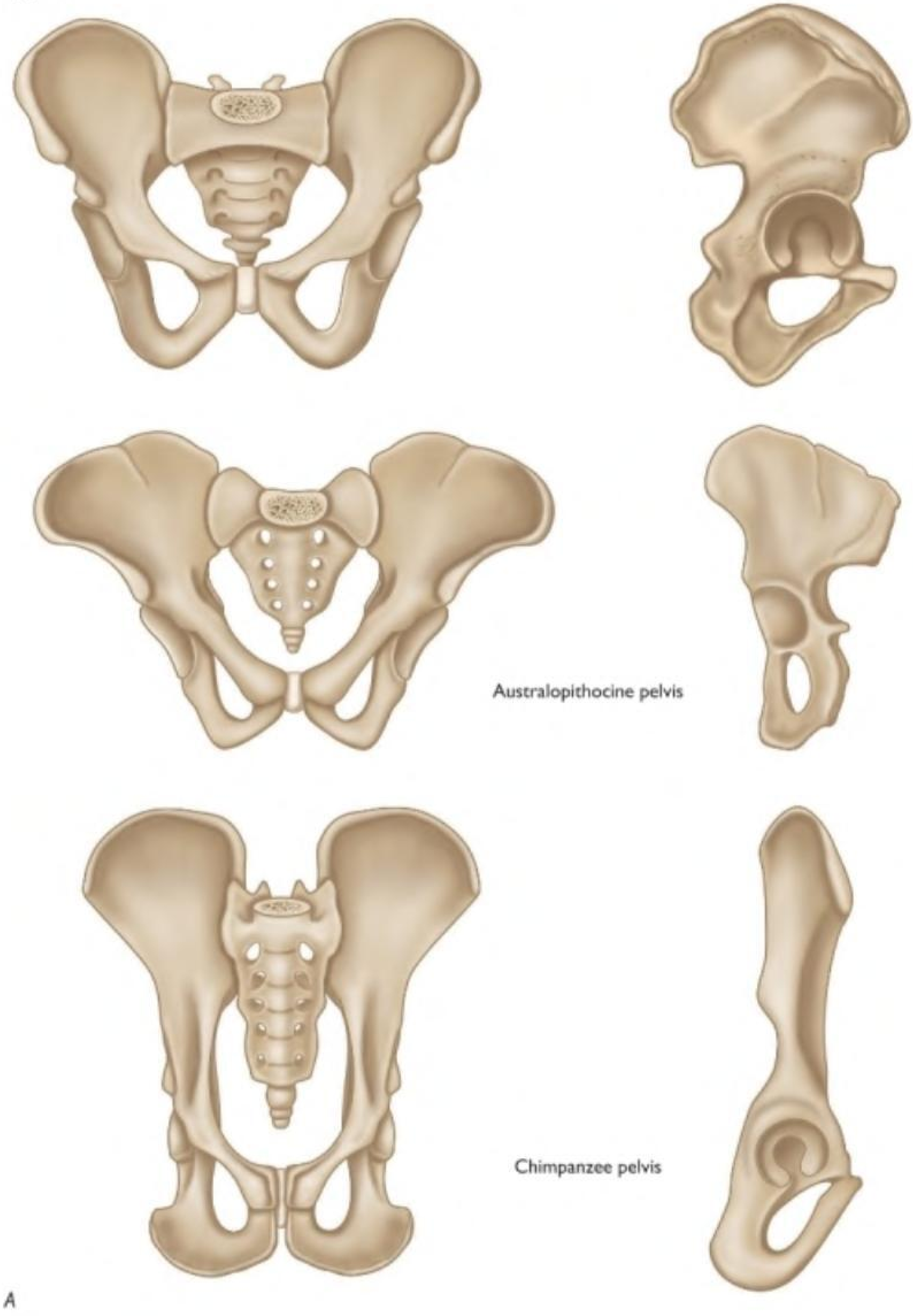


Figure 1.7. Without the constant need for resistance of flexion, the human spinal erectors have a greatly reduced circumference compared to those of the old world monkey (note that the illustration here is a "hybrid" of various species). We can also see how the transverse processes of the human spine are more posteriorly placed, allowing for greater stability in extension, since they are behind the center of the intervertebral discs.

Another important skeletal change in our progression to bipedalism was to bring the ilia into a more lateral orientation. This allows the hip abductors to stabilize the pelvis—in other words, the hip abductors stop us from falling sideways when we stand on one leg (remember, we are on one foot during 80 percent of walking). In all other primates, the ilia face posteriorly, and their hip abductors, especially gluteus maximus and medius, function more as extensors (to push them forward) and give little contribution to lateral stability. This means that they are less able to stand on one leg, an essential part of bipedal gait.



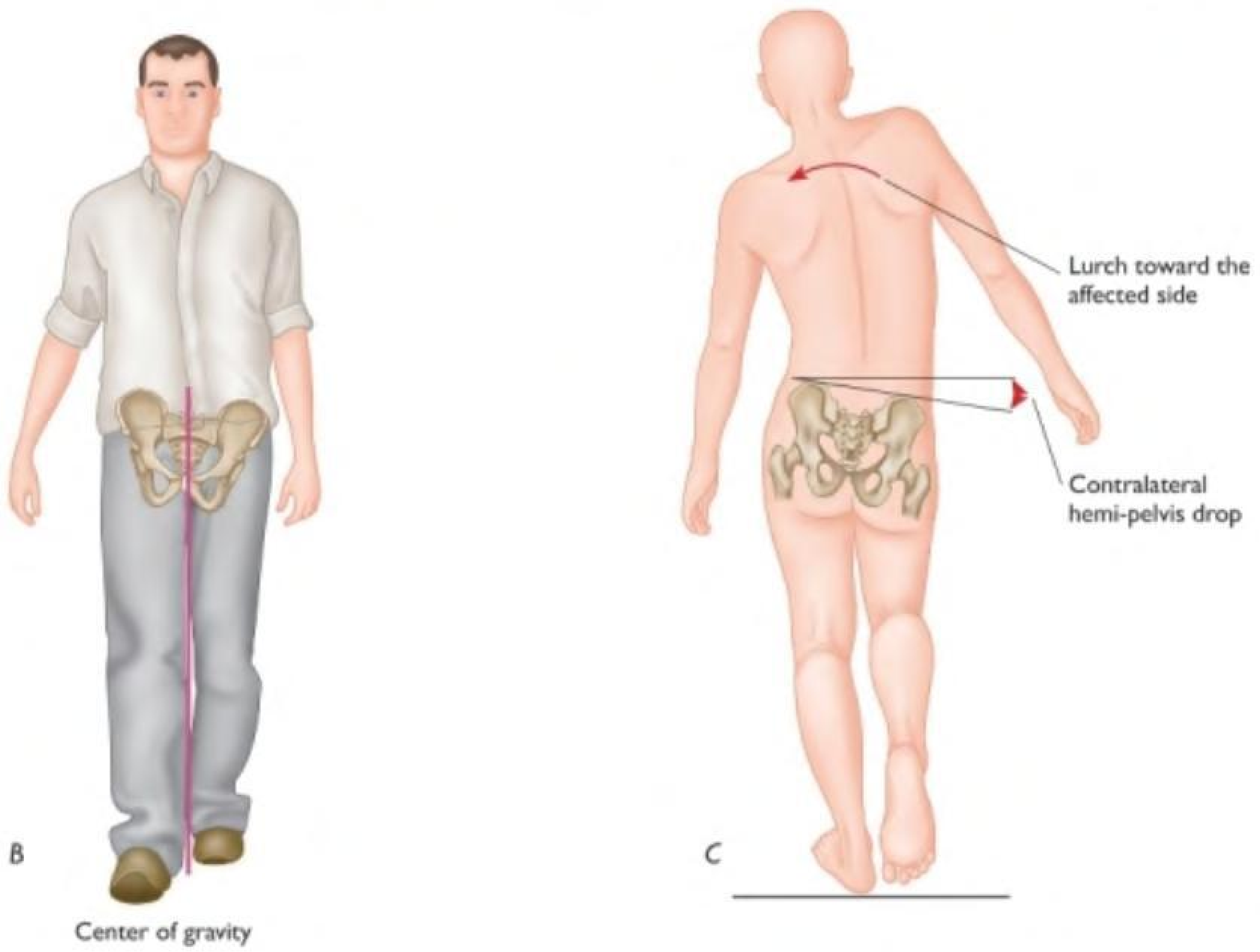


Figure 1.8. As the ilia of the nonhuman primate face posteriorly (A), the fascicular direction of the hip muscles will be more dominant in the sagittal plane, making them work as extensors of the hip, unlike the laterally oriented human ilia (B). When the gluteal muscles are attached at the side of the body, they are able to support the pelvis in the frontal plane and prevent it from falling to one side. Failure of these muscles demonstrates itself in the Trendelenburg gait (C), in which the pelvis falls significantly to one or both sides.

Much debate exists about what makes us "human"—intelligence, language, cooperation, society, opposable thumbs, and so forth—but many people believe bipedalism was the main mechanism for accelerating our evolution as a race. It freed our hands to manipulate tools and to communicate with gesture. Our comparative muscular weakness and our long period of immaturity in childhood demanded better communication, as well as protection and cooperation in group activities, such as hunting. According to Richard Wrangham, the freedom afforded to our hands through our ability to remain upright allowed us to control fire, giving us the unique ability to cook (2009). The preliminary breakdown of food in cooking increases the availability of calories, as less energy is required during digestion. Therefore, we absorb more fuel from the food we eat, making it easier to feed the resource-demanding brain.

The truth is that there is no one factor that led to us becoming human, but the common factor in most of the theories is that we developed strategies to become more efficient. The changes that occurred within our body mechanics permit a high degree of efficiency, which, as Bramble and Lieberman have shown, allowed us to become persistence hunters, chasing our prey to death (2004). In addition, we were able to take advantage of our reduced stomach size (due to cooking our food?), our enhanced thermoregulation (we sweat more than other animals), our greater breathing capacity, and, last but not least, our elastic fascial efficiency.

The changes that occurred in our skeletal alignment allowed us to use gravity and ground reaction forces to great advantage, giving us a more efficient interaction between our anatomy and the forces around it. We see this when we compare the penguin's waddle and an elegant human gait. We don't always recognize the mechanics involved in those differences though, and this will be the further focus of this book: the synergetic alignment of joints, forces and tissue.

Myofascial Design and the Anatomy Trains

The eccentric lengthening of the tissue that is created by the need for shock absorption also helps the body return in the opposite direction, just like the springs of the trampoline. The myofascia is mechanically loaded, like springs, through the momentum created by the forward and rotational forces of walking, as well as by the pull of gravity. This is performed through relatively passive mechanisms (rather than through muscle contraction) that allow the elastic fascial tissue to be put under stretch in all three planes of motion. Due to the angles and positions of the joints in the body, these forces are not restricted to single muscles—they pass through long, continuous chains of myofascia, most often following the lines of "Anatomy Trains," as put forward by Thomas Myers (2009).

After teaching anatomy for many years within the Rolf Institute, Myers began to see that when the network of connective tissue is examined together with muscle fiber direction, one sees continuous lines of force production throughout the body. He first published his "map" of these Anatomy Trains in 1997 and showed how, when the fascial tissue is stretched over joints, it can transfer force across the joint from one myofascial unit to another. When the joints are in midrange, the tissue is relaxed and communication is limited to the single units on one side of the joint (see exercise 1.1), but in certain stretched positions, closer to the end of range, force transmission is facilitated along the myofascial lines across the joints.

Exercise 1.1. First, extend your wrist and fingers to feel the stretch and then compare the sensation and range of motion when you repeat the wrist extension with your elbow also extended. Finally, draw you arm back and into horizontal abduction, keep your elbow extended and again extend your wrist. Each of these movements will engage more tissue across each subsequent joint. They may or may not affect the range of motion, but the sensations should differ as one brings into play more of what Myers refers to as the Superficial Front Arm Line.

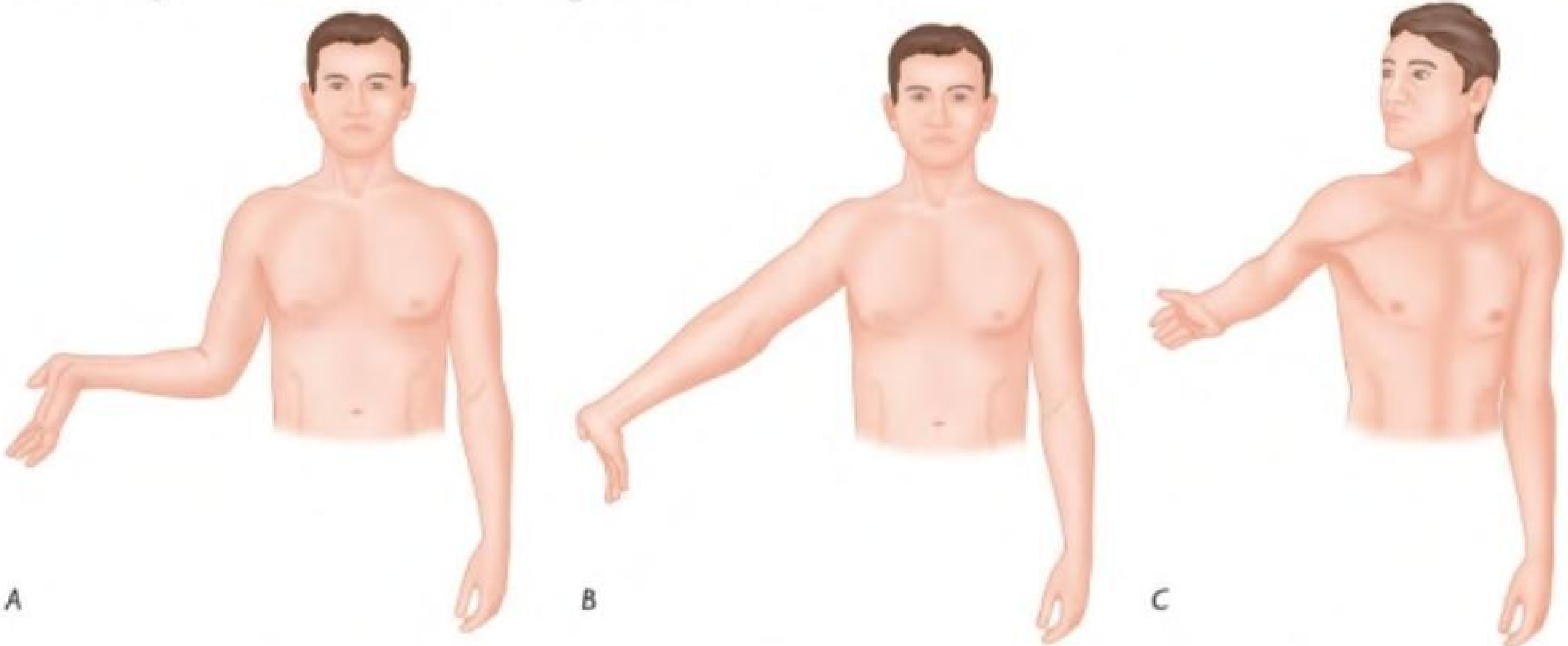


Figure 1.9. By engaging the tissues across the wrist (A), then elbow (B), and finally the gleno-humeral joints (C), each wrist extension will feel differently as more of the Superficial Front Arm Line is brought into the movement. Experiment further by changing the position and angle of the humerus and noticing the effect on the stretch of the wrist flexors. You may find there is a certain angle and position that feels as if it includes the whole of the line. It is this mechanism—the proper positioning that engages the full myofascial line—that we wish to exploit in walking.

When longer myofascial lines are engaged, one part of the body can affect another. Just as the shoulder position affects the hand and wrist in exercise 1.1, so too will the pelvis affect the foot; and the head, the thorax. By visualizing these continuous lines of force through the body, we can interpret the effects of one part on another, understanding how, for example, the shoulder position may affect the tracking of the knee. This will, hopefully, lead to ways of correcting inefficiencies in walking.

Just as we need to consider both the voluntary action and the involuntary reflex reactions of the myofascial system to understand walking, so too do we have to see the myofascial system in terms of both individual muscles and long continuous chains of linked myofascial units. These chains, called "lines" or "Anatomy Trains," allow a long section of the body—rather than, say, an individual muscle in the leg—to contribute to shock absorption and its control, and this provides longer elastic chains that absorb kinetic energy and then recoil with elastic force, thereby allowing for greater energy conservation (see fig. 1.10, overleaf).

Figure 1.10. At heel strike on the right side, the downward force from the trunk creates a tilt of the pelvis to the left side. This "acceleration" (the sudden tilting to the left) will be perceived and controlled by the hip abductors on the right—the side of heel strike—and the lateral abdominals on the left. Neither the contraction nor the fascial loading will be restricted to just those named muscles, but will go farther along what Myers has named the "Lateral Line."

Myers built this Anatomy Trains model on previous and similar work done by earlier anatomists—such as Dart, Vleeming, and Busquet. He charted a comprehensive map of the biomechanical chains through the body. His work focused on the posture of a person standing still, and initially, the fuller implications of Anatomy Trains in movement were less appreciated. But when we analyze the interactions between gravity and ground reaction force, the continuity of the myofascial system really comes to life. This system lets us track the forces involved in the body in each plane of motion and at differing layers of the body. The Anatomy Trains also show us the tension-adjusting system that helps to disperse the forces the body is exposed to—spreading the "shock" and also, vitally, recruiting distant areas to assist in recovery. This interrelationship of the disparate parts of the body is our key to efficiency, and its understanding helps us to visualize the "walking system."

Tensegrity

We can now begin to see the interplay between the strength and stability of the skeletal system and the adaptability, buoyancy, and tension abilities of the myofascial system. This new model of the human body gives us a way of understanding these integrated systems and how they collaborate to distribute tension and organize response. "Tensegrity" is at play every time we move; it is inherent within our body as far down as the cellular level, but there are few everyday expressions of it more tangible than the poetic, full-body movement of walking.

Figure 1.11. When we see the body represented as a tensegrity system like this, with just the musculoskeletal elements presented (in vague approximation of reality), it is easier to comprehend how the body interacts with its environment to dissipate and produce force.

The use of solid elements (bone) and elastic elements (myofascia) requires the presence of a certain amount of prestress. It is the contribution of "tension" that gives the structure "integrity" (and it is the combination of these two words that Fuller used to coin the term *tensegrity*).

One of the characteristics of tensegrity structures is their ability to distribute stress or changes in tension throughout the whole of the structure. This can be either a positive or negative thing, depending on the nature of the change. Too much tension will lead to an increase in stiffness and possible breakdown, while a decrease in tension can cause the structure to lose some of its integrity. Balanced tension allows resilience in the system, giving it the ability to disperse, communicate, and store forces across itself and still maintain equilibrium. This is the essence of what therapists aim to achieve when intervening with a patient's gait: we first need to recognize the imbalance or inability to communicate mechanical force, and then, by appropriate intervention, bring the patient's system to resilience.

While there is some debate over the full application of tensegrity in biological structures, there does seem to be an ever-increasing amount of acceptance of the concept. Tensegrity gives us a framework to explain many aspects of human and animal movement. In doing so, we have come full circle, once again using the understanding of architectural structure and geometry to describe human form.

Don Ingber, a researcher at Harvard Medical School, was the first to apply this new geometrical concept to the body, beginning in the 1980s. Ingber showed how cellular structure and mechanics can be explained through tensegrity. Cells have their own inner supports, which allow the transfer of mechanical forces. These forces can communicate cell shape to the nucleus and thereby influence cellular expressions (Ingber 1998).

Steven Levin, a retired orthopedic surgeon, took this a step further and demonstrated that the pelvic and shoulder girdles and the knee joint are using similar engineering principles. He argues that tensegrity is the essential building mechanism at the level of the cell, the tissues, and the entire body. Adding to Ingber's ideas on the laws of self-assembly (the ways in which the cells combine), many consider that tensegrity elements will follow their natural mechanics and attach to one another to grow ever more complex communities, all following the principles of "tensional integrity."

The sacrum is often illustrated as a keystone that gives the pelvis a compressional locking force, using the cumulative weight of the bones from above to hold the pelvis together. Alternatively, it is described as acting like an arrowhead that would split the two sides of the pelvis apart. When the pelvis is examined in cross section (see fig. 1.12), however, the sacrum is clearly shown to be suspended between the ilia. It therefore helps draw the two sides of the pelvis together, using tension from the myofascial guide-wires. In chapter 5, "Spiral Line," we will see that the "flotation" of the sacrum between the ilia is essential in mediating the many forces that come from the upper and lower bodies. The sacroiliac joints act as a hub for force mediation through the pelvis.

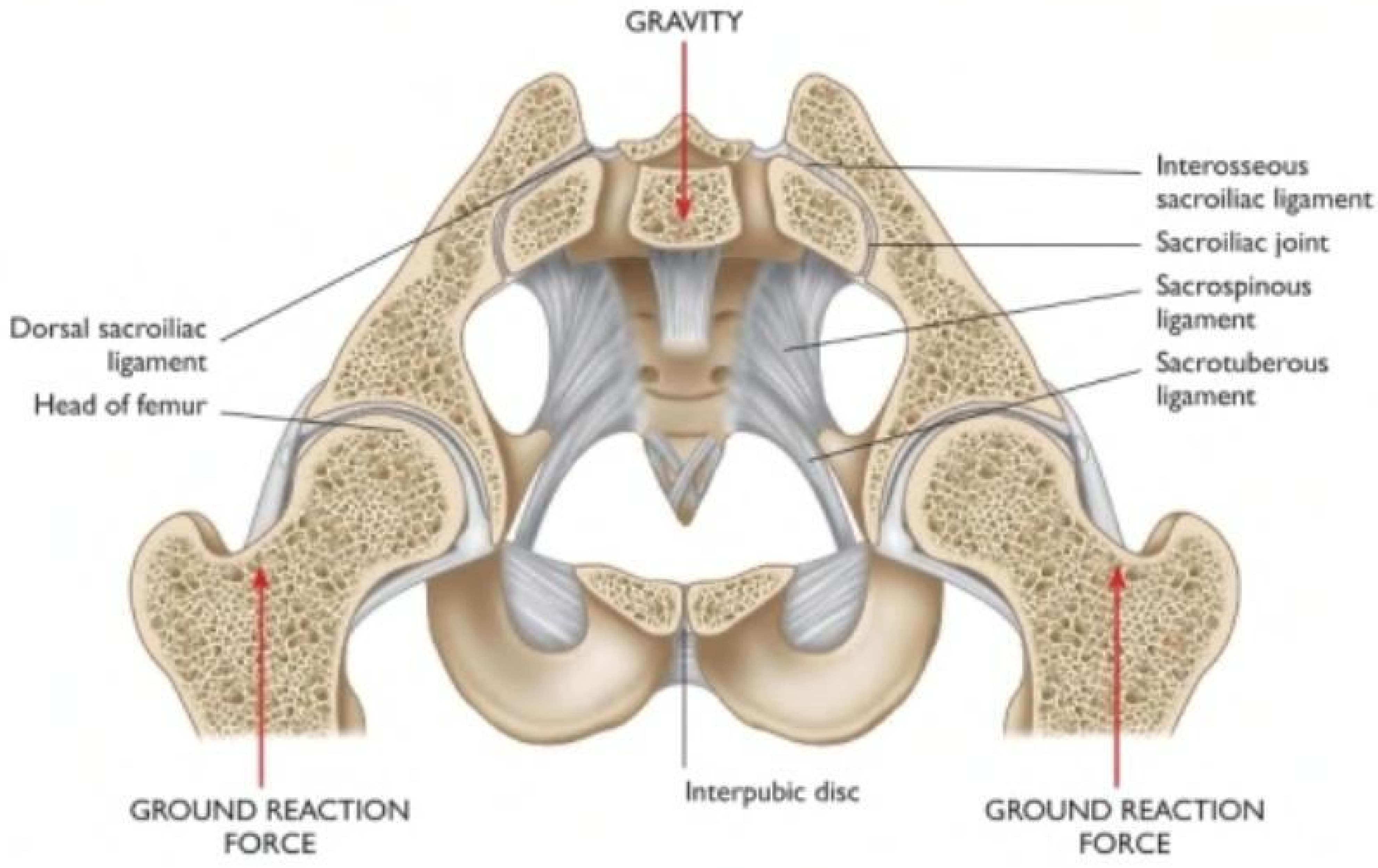


Figure 1.12. When seen in cross section, it is clear that the sacrum is suspended from the ilia, like a hammock between the trees of the ilia; the dorsal sacroiliac ligaments are akin to the ropes of the hammock. Levin argues that the sacrum has to act within the joints to mediate the various forces coming from above and below—gravity and ground reaction force (yellow). Furthermore, he argues that the sacrum is supported in the tension created by the "approximation" force (the force that draws two sides together) of the dorsal sacroiliac ligaments (green), rather than by the compression of the ilia. That is, it is a tensegrity structure (in Vleeming et al 2007).

As discussed above, any force applied to a tensegrity structure is dispersed through its entirety, and when we look more closely at distortion, we see two very important phenomena. The first is that tension elements align themselves along the line of pull, helping to increase resistance along that line—effectively making the structure stiffer (and therefore stronger) as more lines are recruited to oppose the stress. This is an important feature of many biological tissues—they get stiffer under stress, meaning that the stronger the force, the more resistance they have.

A second characteristic of tensegrity structures is that once the strain is removed, the structure returns to its normal resting balance. Tensegrity structures are therefore self-supporting, not requiring the addition of gravity to maintain or hold their form (compared to a tower of blocks, which requires the compression of gravity and loses all integrity when turned at an angle to gravity). Tensegrity structures have an internal resilience that absorbs the energy of external forces and then uses it to return to neutral. The human body applies this dynamic in efficient walking, using the interaction of momentum, gravity, and the resistance from the ground to tension the tissues, and as the body position changes, this tension is released to assist with the return movement, somewhat like a watch-spring mechanism.

TRIANGULATION

By standing upright, humans have taken fuller advantage of one of tensegrity's dynamic characteristics. We are less stable by having only two contact points with the ground, and we further exacerbate that instability by balancing on one leg during 80 percent of walking and 100 percent of running (excluding the flight phase of running, when we have no contact with the ground). To manage this acrobatic act, we have changed the way in which the forces pass through the body, allowing for much more three-dimensional variation.

In the tensegrity of the upright body, the compression elements (the bones) are supported by the elastic, tensioning forces (the myofascia). The vectors of support are arranged in a triangulated pattern following mathematical laws similar to those of crystal formation. As Levin shows, a triangular truss is much more able to disperse force within itself than a square frame (in Vleeming et al 2007, see fig. 1.13). This is important to keep in mind, as the body rarely uses movement in just one plane of motion, making it difficult to track events as we go through a movement. Tension is created in each plane: frontal, sagittal, and transverse. I will simplify this in the book by dealing with each in turn, but they are all acting simultaneously.

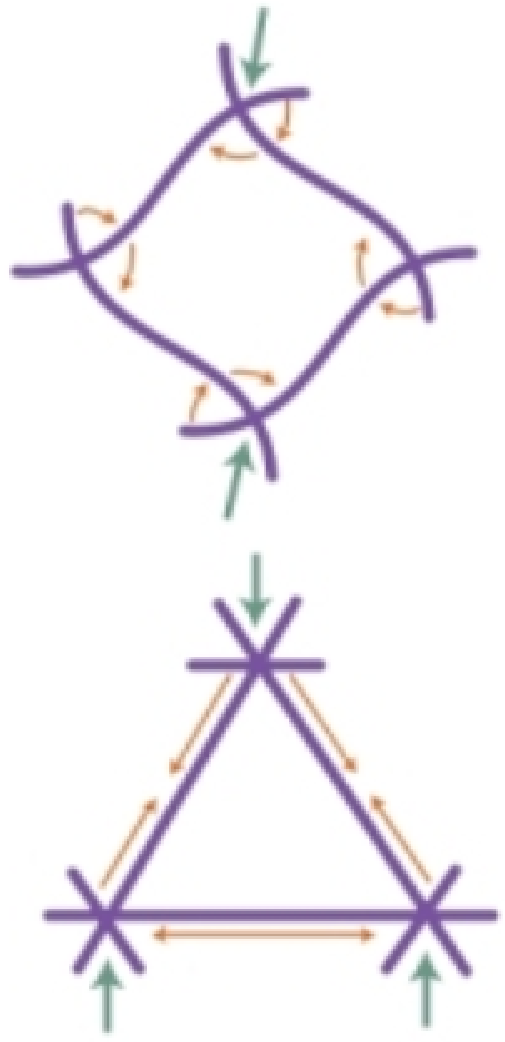


Figure 1.13. A square-based arrangement will tend to buckle under stress, compared to a triangulated structure, which is able to deal with both compression and tension along its axis.

When tensions in the body are balanced, there is a sense of effortlessness; the bones are "floating in a sea of tension," as Myers said, and any changes in that equilibrium will be easily absorbed and recoiled back with the natural resilience of the tissue (2009). It is easy for us to imagine the muscular system as the controllers of this tensioning, but the muscles are only one element of the supportive tissues that hold the bones in place. The primary tissues of the system are the fascial tissues. The muscles are essentially the fine tuners of the system, adding or subtracting tension when needed, via the fascial tissues of the body.

FASCIAL MEMBRANES

As mentioned earlier, each and every part of the body is wrapped within the fibrous, fascial web of connective tissue, which consists predominantly of collagen, elastin, and ground substance (a gel-like fluid consisting of water along with various sugars and proteins). The fascia holds each and every part of our body together and it provides us with protection, both mechanical and chemical—the fascia forms a physical barrier, and the fluid within the fascia contains many lymphocytes. The fibrous elements allow the transfer of force (created either by muscle contractions or external forces), but they do so with an element of elasticity, which gives us the "spring in our step." This pliability is enhanced through the engagement of longer lines of tissue, the connections of one myofascial unit to another and another, such as those felt in exercise 1.1.

Force is most often considered in terms of straight lines, along muscle fibers and out into tendons and ligaments. This bias is inherent within the presentations of the Anatomy Train lines, but it is a misunderstanding, as we need to regard fascial aponeuroses and consider that the Anatomy Trains are communicating through these tissues as well.

Many of the fascial wrapping sheaths in the body are extensions of muscular tissue. These often play an important role in dispersing force by acting as "hydraulic amplifiers" (Gracovetsky 2008; DeRosa and Porterfield in Vleeming et al 2007). To understand a "hydraulic amplifier," imagine the example of a balloon. The tension of the outer rubber membrane and the compression of the air inside it create a "stiffening" dynamic within the structure. If the balloon is not fully inflated, however, there will be little tension created on the outside. The balloon will be less resilient and will mold itself to the surface it is resting on, rather than being independently buoyant on it. Conversely, if the balloon is overinflated, the rubber becomes fatigued and will lose its ability to adapt to the tension—it will burst. In the fascia, the body's encasing material, similar events can occur.

This has been studied primarily in the thoracolumbar and thigh areas, where the muscles of the pelvis and the lower back are dealing with high stress loads in various vectors of force and at different anatomical depths (see fig. 1.14, overleaf). In cross section, we can see the continuity of the posterior and middle layers of the thoracolumbar fascia wrapping around the muscles—stabilizing, supporting, or moving the lower back.

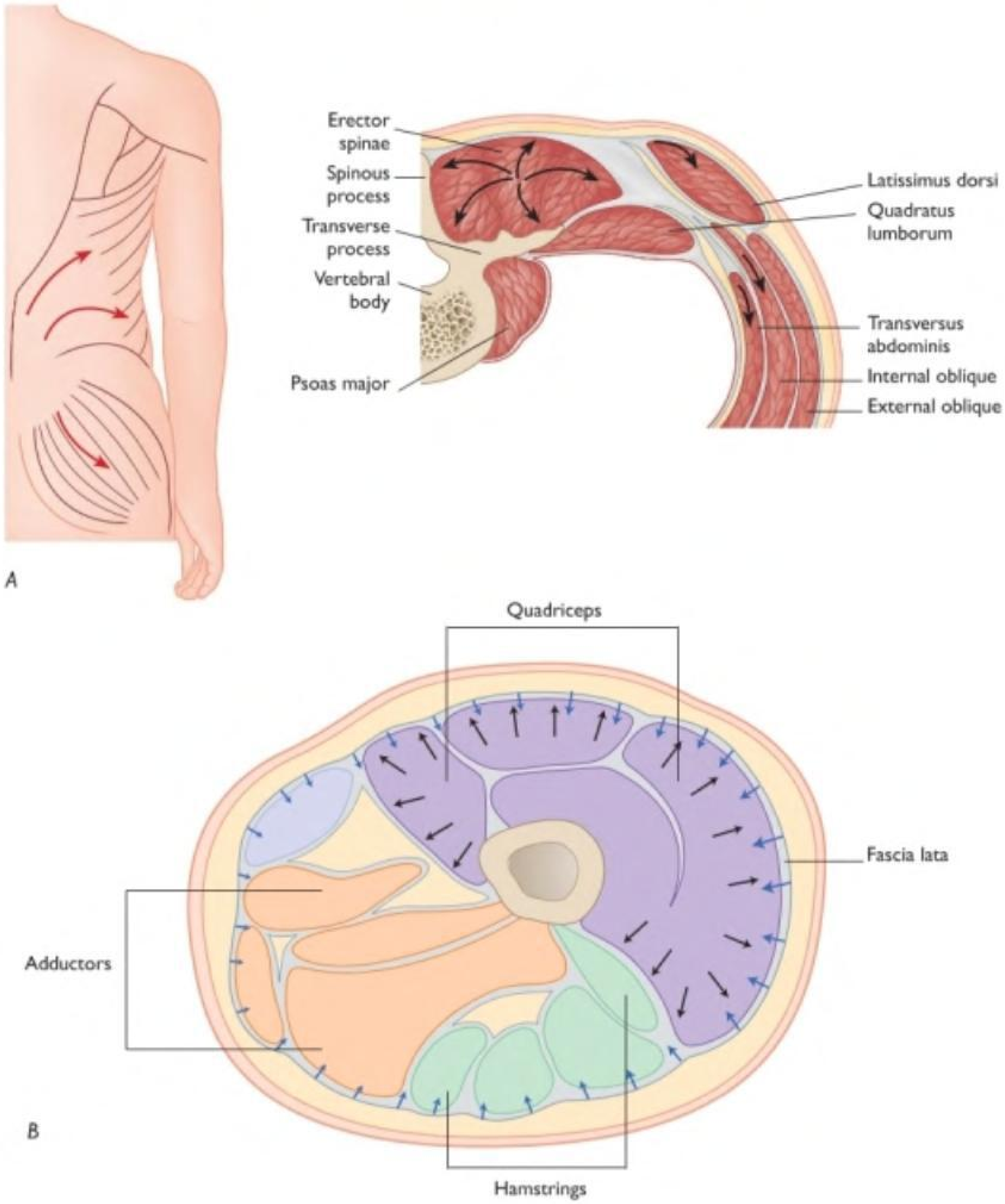


Figure 1.14 In walking, the thoracolumbar fascia will be tensioned by the contralateral contraction of the gluteus maximus and latissimus dorsi. This creates tension in the supporting fascia around the lower back muscles, which in turn "pump up" the fascia by pushing out against it when they contract to support the spine. This creates a force-dispersal system and is a mechanism used in various parts of the body, including the thigh (B). The enveloping fascia of the thigh, the fascia lata, is tensioned by the appropriately named tensor fascia lata and by the gluteus maximus. Both of those muscles are, in fact, encased within that layer of fascial tissue. This inward force is then matched by the outward expansion of the underlying muscles, which will be contracting to support the knee and hip.

In walking, there is tensioning of the gluteus maximus and latissimus dorsi muscles, which are connected via the thoracolumbar fascia. This fascial sheet and its deeper connections will therefore be tensioned, like the skin of a balloon, and this "shrink wrapping" force will meet the expansion of the muscles within it, creating a taut "balloon" capable of easy force transfer and recoil. It is estimated that this form of hydraulic amplifier can increase the efficiency of muscle contractions by up to 30 percent, though if the fascial sheets are challenged, as in a fasciotomy (the cutting of the fascia to relieve underlying pressure), efficiency can be decreased by 10 percent to 16 percent (Parker and Briggs 2007).

All of these myofascial layers, while separate in terms of depth and the forces they carry, are connected to one another by a different kind of fluid-rich fascial tissue, known as "areolar" or "loose connective" tissue. This tissue provides the lubrication within the system that enables each plane to glide on its neighbor. This tissue can sometimes can be prone to changes in local hydration, creating adhesions which inhibit the relative movement between the different planes.

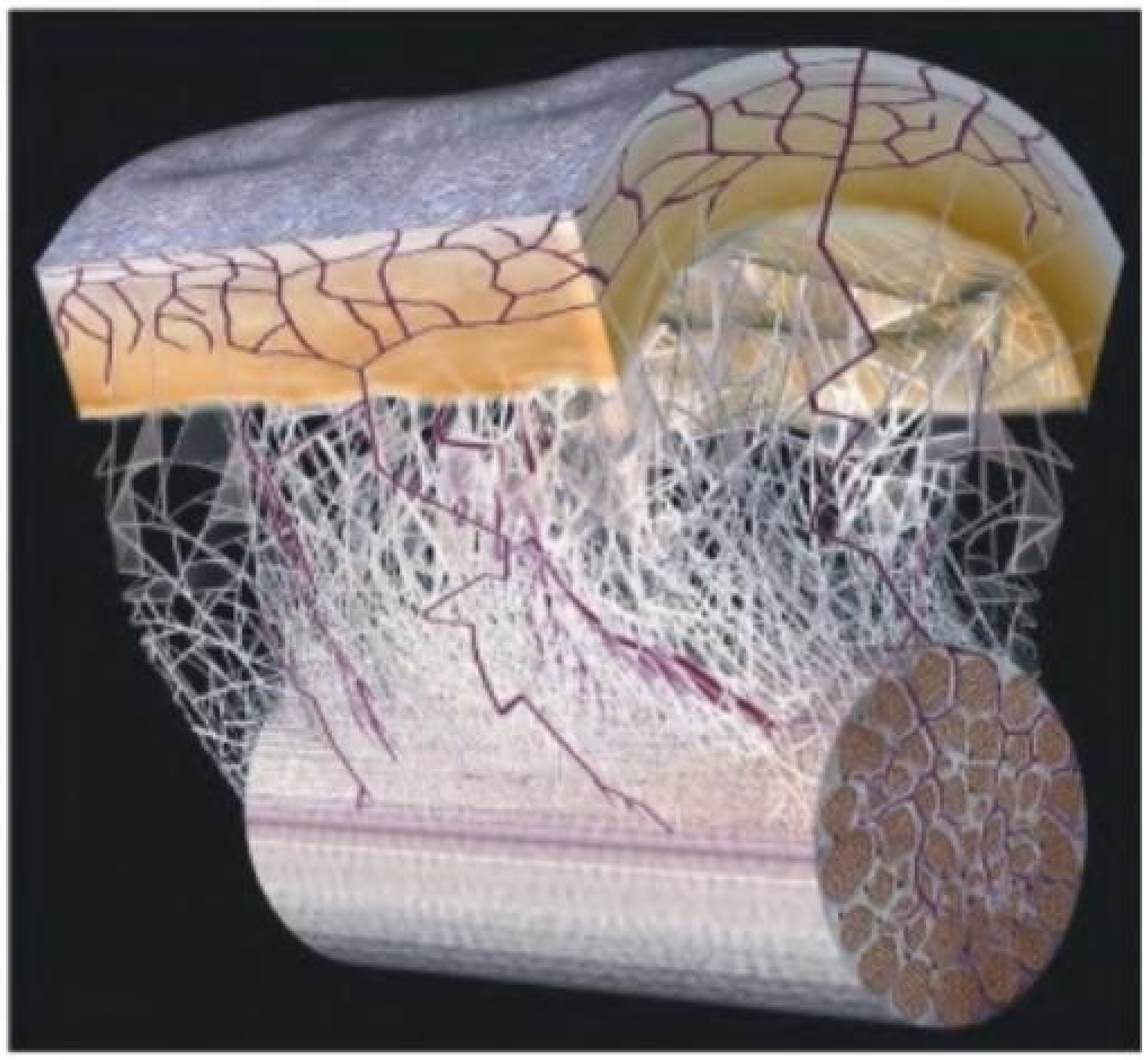


Figure 1.15. The very fluid areolar tissue contains collagen and elastin fibers, like fascia, but within a much higher concentration of ground substance. This compliant tissue connects fascial layers and facilitates movement by adapting its orientation to the vector of forces involved. Reproduced with the kind permission of Dr J.C. Guimberteau and EndovivoProductions.

STIFFNESS

Stiffness, not the early-morning type of stiffness that increases with age, but rather the tissues' resistance to deformation, is an essential feature of the body. The body's skeletal structure is inherently unstable, and each bone interfaces with another on curved surfaces. One role of the soft tissue is to give resistance, or stiffness, to the system, to ensure that it doesn't collapse under the pressure of external forces.

It does this in a number of different ways. First, there is the mechanical influence of the collagen and elastin fibers that hold everything in place (see fig. 1.16). Both types of fiber are "elastic," able to stretch beyond their normal resting length and then return to their original resting length. Elastin is able to lengthen more than the collagen, but collagen, when stretched, will recoil back to its neutral with more efficiency. What this means is that collagen is truly more "elastic" than elastin, as it gives more elastic energy back into the system.

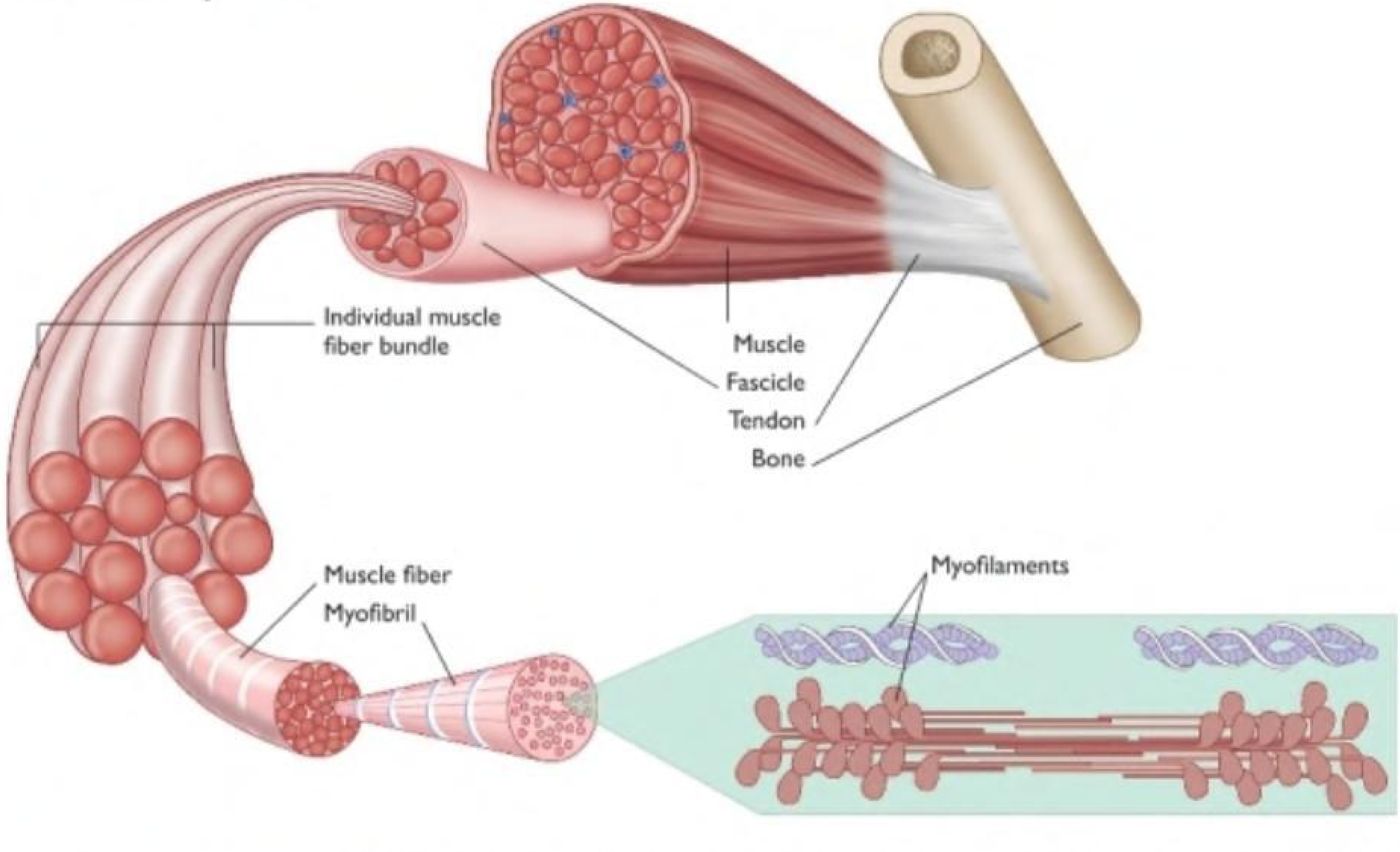


Figure 1.16. Each muscle is encased within a series of fascial bags—the epimysium, perimysium, and endomysium—which are made up of various types of collagen fiber, with a blend of elastin and the more-fluid ground substance.

To explain the importance of this, we need to look at normal movement. A number of experiments have shown that during repetitive movements such as walking, there is very little change in the length of the muscle fibers, which are often used in *isometric* contraction (i.e., they are not becoming shorter when they contract—they are simply maintaining their current length, see fig. 1.17). The lengthening required during walking actually occurs in the fascial tissues, in the collagen and elastin, which are able to recoil from the stretch and return to their resting length, like a spring.

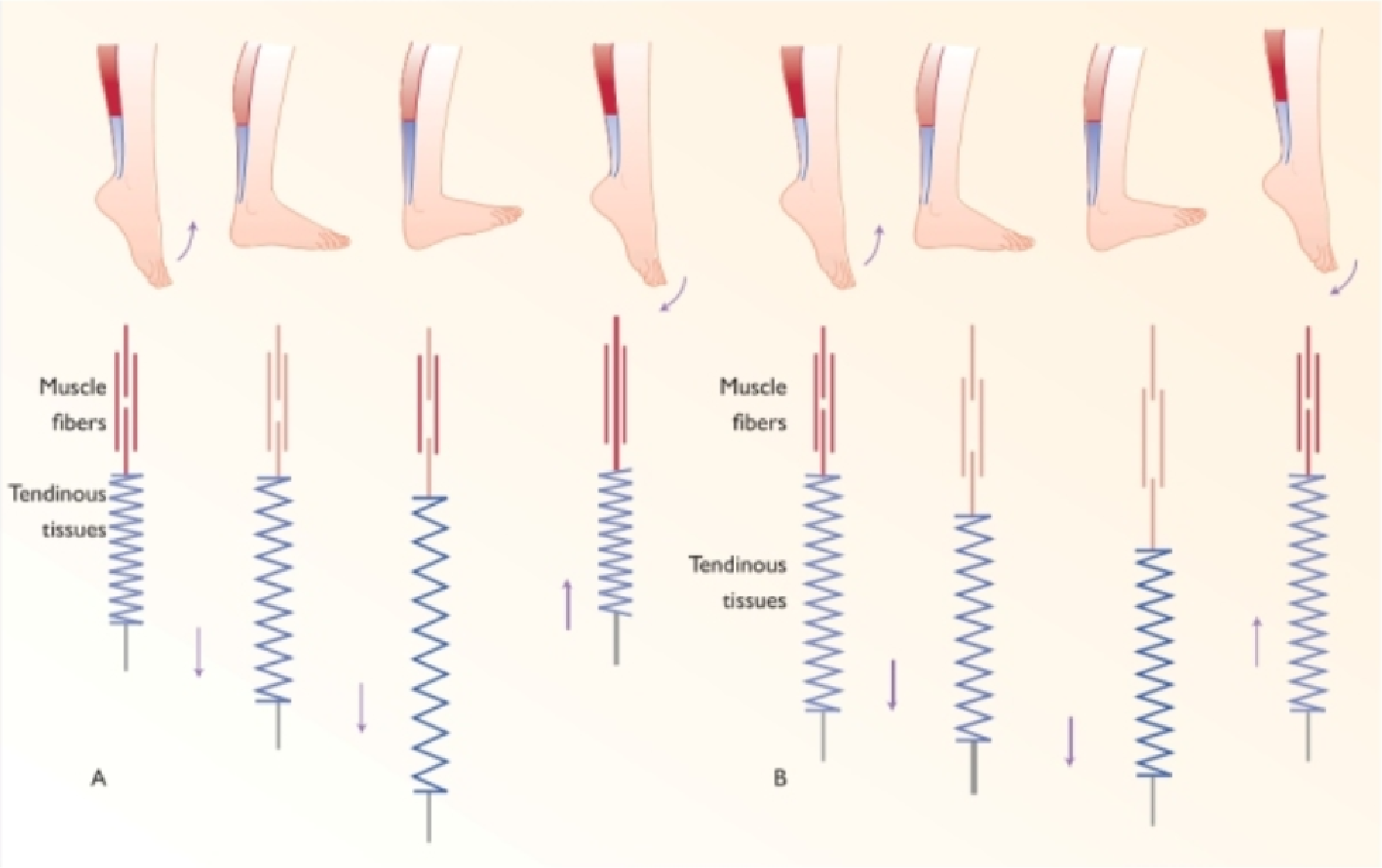


Figure 1.17. In this diagram, the fascial tissue is represented as the "elastic" tissue (using Hookean springs) and the contractile muscle as sliding filaments. In a series of experiments, Fukunaga and colleagues showed that in cyclical movements the muscles tended to remain predominately isometric (A) rather than doing the extra work on concentric and eccentric contraction (B), 2002 and 2006.

The main benefit of this arrangement is that the recoil of the fascial tissue is providing essentially free energy. The fascia is stretched by the interaction of the body's momentum and its interaction with the ground. If the actin and myosin filaments (the sliding elements within the muscle fibers that control contraction) do not allow the muscle to lengthen, then the forces involved in movement have to be absorbed by the fibrous tissue. The fascial tissue is transforming kinetic energy into potential energy by absorbing energy and then releasing it back into the system as kinetic energy again. It is impossible to give exact figures for the amount of stretch and recoil that is produced in each fascial tissue, because it varies widely in different parts of the body, but it can be as much as 93 percent of the energy being given back into the system (McNeill Alexander 2002).

Once again, we see the body's drive for efficiency come into play. The active concentric and eccentric contraction of muscles is expensive, requiring the exchange of adenosine triphosphate (ATP) and glucose. Much less fuel is required when muscle fibers are held in isometric contraction. One of the hallmarks of efficient walking is the absence of active muscular contraction, maximizing the recoil efficiency of the fascial tissues; an easy walking pattern should use only around 38 percent of the body's maximal aerobic capacity.

FASCIAL EFFICIENCY

I can remember walking as a child. It was not customary to say you were fatigued. It was customary to complete the goal of the expedition.
—Katharine Hepburn

What the role of fascia in walking means is that we need to change how we think about muscles. The old idea of movement via concentric, eccentric, and occasional isometric contraction is just not how the body works in many functions. The muscles work as a stiffness adjusting system. Just as a Pilates instructor changes the springs on a reformer to suit the client or the exercise, so too does the neuromyofascial system adjust the springs to match the forces in the tissue, a constant computational task and one that we still fail to fully understand.

As discussed above, the body needs something to hold it together; it is a bag of bones that, due to their slippery ends, require additional support from the surrounding tissue. The joints—the interfaces between the bones—fold, bend, flex, rotate, or extend in predictable directions. They are therefore able to guide the forces in the body: when the quadriceps contracts, the force is transmitted via the patella to extend the knee. However, when we look at the interaction between the body and the ground, the relationship is reversed: it is the bending of the knee on impact that sends the force to the quadriceps, sparking its contraction.

This reversal of function is important. When we look at movements involving some form of impact with a surface, it is the channeling effect of the joint that creates the movement, not the muscle. The joints are like dry riverbeds that direct the water through the landscape via the path of least resistance. Any movement that creates a normal impact on the body, such as heel strike in walking, will require the deceleration of momentum (and I will outline the many ways the body does this in the next chapter by tracing the action across the major joints involved in walking).

Using the conventional eccentric/concentric contractions of muscles for each step would require a large amount of resources. The body would have to constantly bind and unbind the actin and myosin filaments of the muscles. We often feel the effects of this muscular type of movement when we go for strolls involving a lot of stopping and starting, such as meandering around a museum or shopping with loved ones on a Saturday afternoon. The constant stopping and starting requires more muscular effort and is therefore much more tiring than going for a long, evenly paced walk, which allows other, more efficient mechanisms to come into play.

In the repetitive motions of walking, the inner tuning of our springs is unconscious. Apparently even the spinal cord is rarely involved in controlling the movement—it is the local relationship between the mechanoreceptors in the fascial tissue and the surrounding "adjusters" of the muscles that are in charge. By finding the most efficient level of stiffness, the body can maximize the use of elastic recoil and minimize the metabolic costs.

Deformation and Elasticity

Could the young but realize how soon they will become mere walking bundles of habits, they would give more heed to their conduct while in the plastic state.
—William James

As we saw in the Fukunaga experiments reported above (see fig. 1.17), the force-guiding effect of the joints will lead to *deformation* of the myofascia in repetitive motions such as walking. *Deformation* is defined as any compression, shear, or tension. I will concentrate on the production of tension that creates stress in the tissues and thereby lengthens them. The amount the tissues lengthen depends on a number of factors, including age, hydration, and nutrition, but it also depends on the quality of that tissue, as not all myofascia is the same. Some myofascia will have more connective tissue, and this will affect its elasticity (its ability to lengthen and return to its original position). For example, there is an obvious difference in the architecture of the gastrocnemius, the sartorius, and the semimembranosus (see fig. 1.18, overleaf). The passive force curve (which measures the elasticity of the connective tissue in each muscle) illustrates the greater stiffness of the gastrocnemius and shows how its resistance to stretch begins sooner than in the sartorius or semimembranosus. This means that the connective tissue of the gastrocnemius is stretched earlier in its movement, and it requires more energy to be lengthened, an important feature for economy of gait.

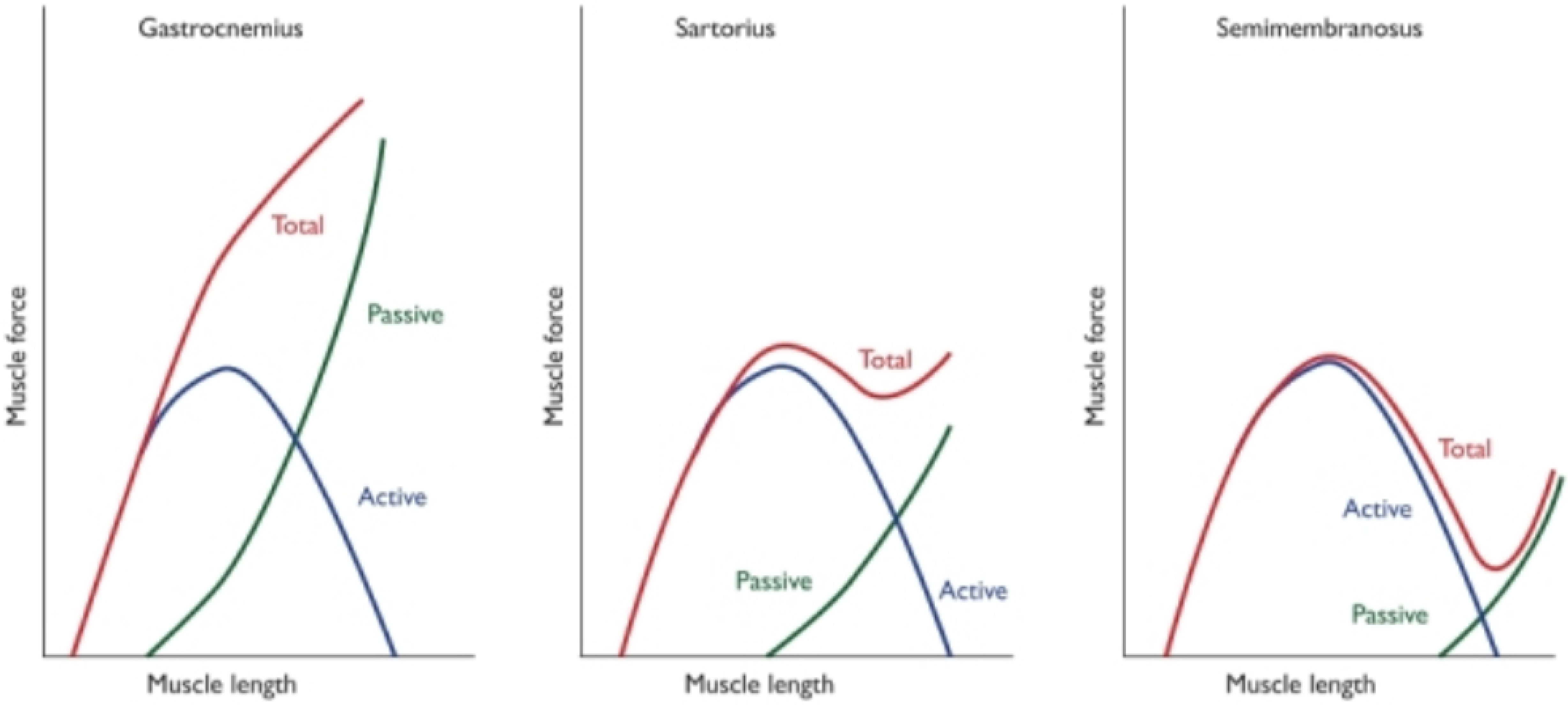


Figure 1.18. Based on work done by Wilkie in 1968, Komi (2011) points out that the gastrocnemius has shorter fascicles, which means that it will be less able to stretch than the longer-fibered thigh muscles of sartorius and semimembranosus. This will send the force of that stretch into gastrocnemius's connective tissue at a shorter range of motion (the gastrocnemius has more connective tissue for this reason). Areas of the body with higher mechanical stress will use a number of strategies to deal with the extra loading. One of those is a greater amount of connective tissue, which protects the area and allows the force to be absorbed and returned as energy. We will also see later that the pennation, in which the muscle fibers attach to the tendon at an oblique angle, adds efficiency to this system.

By elongating the connective tissue of the gastrocnemius, for example, we are creating a store of energy. Most organic materials have some form or amount of elastic ability; they are able to stretch (deform) and then return to their original length. The obvious example is a rubber band, which requires work to stretch but then will recoil to its original state by itself. If you pull a rubber band, you feel the energy required to stretch it, and if it snaps back against your fingers, you will certainly experience the energy available in the return. In the case of the body's movement in walking, the elastic tissue is stretched ("loaded") quite passively, through the natural pressure of gravity and ground reaction force.

The amount of energy returned with the recoil does not always match that which created it (some energy is lost in the system), but in terms of economy, connective tissue is quite efficient: up to 93 percent of energy is returned to the system. This means that a lot of the energy being used in walking is almost "free"—it does not require the active contraction of the muscles and the use of oxygen. Some measurements have calculated the about 17 percent of the force required in running comes from the recoil of the arches of the feet, and 16 percent of walking from the Achilles tendon (Blazevich 2011).

The loss of energy from the system is referred to as *hysteresis* (see fig. 1.19). Some energy loss is due to the *viscosity* of the tissue, which is its resistance to deformation. This varies considerably, depending on the chemical nature and make-up of the tissues involved, all of which can also create slight delay in tissue recoil.

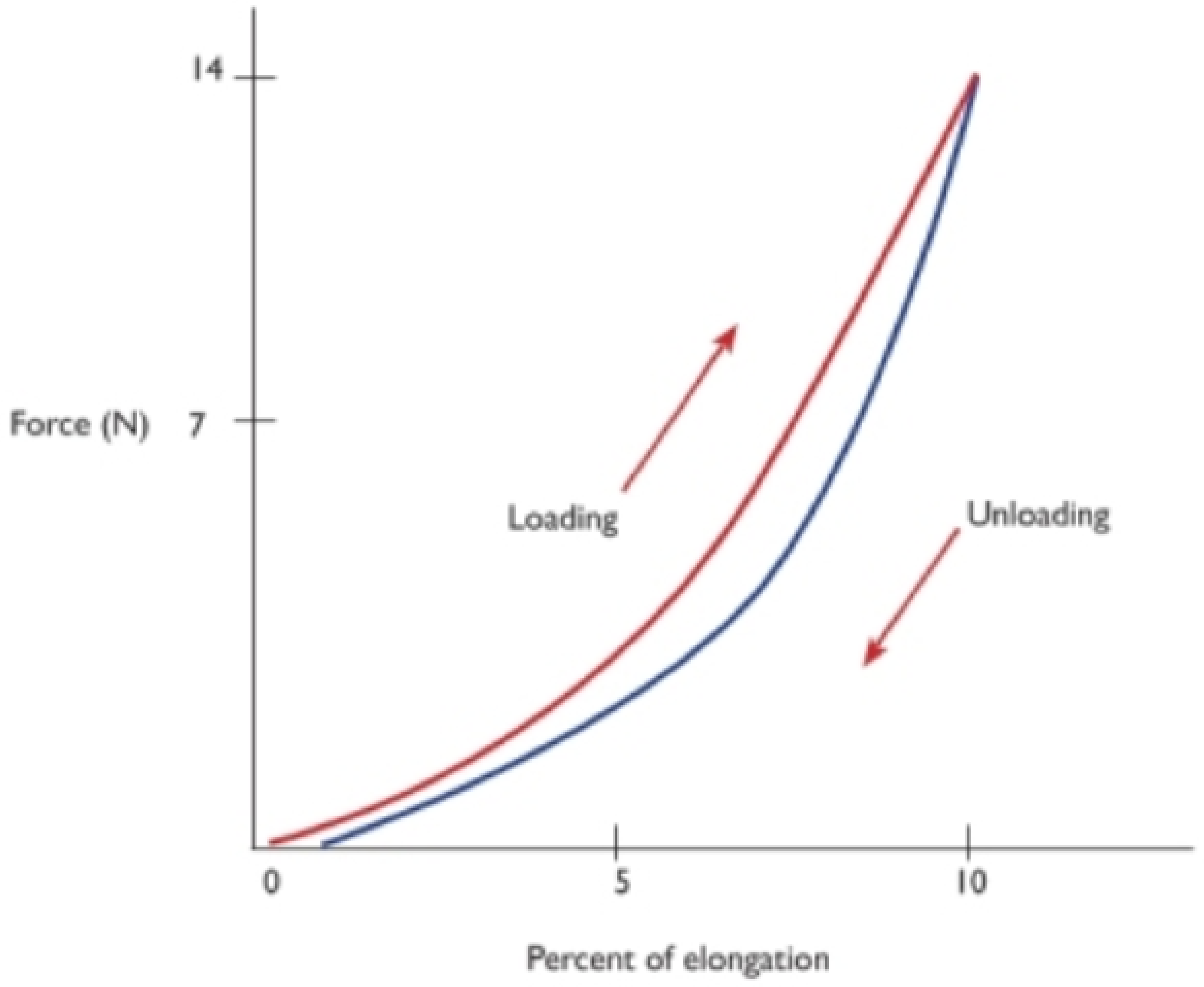


Figure 1.19. The graph illustrates the nonlinear nature of the amount of force required to stretch connective tissue (i.e., more force is required for the second centimeter of stretch than was needed for the first). The hashed line underneath maps the tissue's elastic return to resting length. In a truly efficient system, the two lines would match (i.e., the same force would return to the system). The gap between the two lines illustrates the lost energy due to hysteresis, an inherent property of the tissue.

Viscoelasticity

The viscosity within the connective tissue is a double-edged sword: while it robs us of some of the available recoil energy, it also absorbs a portion of the body's momentum, particularly in its struggle against gravity, and by doing so, it removes some of the workload from the muscles. Connective tissue is often referred to as *viscoelastic* because of this combination of properties.

The fluid element within fascia, the ground substance, is made up of proteins and sugars (glycosaminoglycans) and behaves in a nonlinear fashion. Sometimes referred to as a non-Newtonian fluid (so-called because it does not react to forces in a linear, "Newton-approached" fashion), the ground substance can become "stickier" and, when force is applied at speed, can provide more stiffness for the system.

You may have felt this reaction when comparing a Hatha yoga–type slow stretch to a plyometric exercise. The sharper, faster movements of the plyometrics create a strong and often linear response in the tissue compared to movement entered into slowly, which has a more dispersed effect. The viscosity can be affected by a number of factors, including heat (compare a Bikram yoga class to stretching at the North Pole) and the hydration of the tissue (the ground substance is extremely hydrophilic and needs to bind to water molecules to maintain fluidity). This mechanism comes into play during walking: when a joint is encouraged to move in the deceleration phase—after heel strike, when the system is working to absorb the force of gravity and the ground reaction force—the viscous ground substance will stiffen the tissue and thereby allow the fascial fibers to load more, taking further advantage of the elastic recoil.

Stretch Reflex

The elastic stretching of the tissue also stimulates many of the body's mechanoreceptors, the proprioceptors for the body. The muscle spindle, in particular, sensing the stretch within the myofascia, will set off the stretch reflex arc (see fig. 1.20).

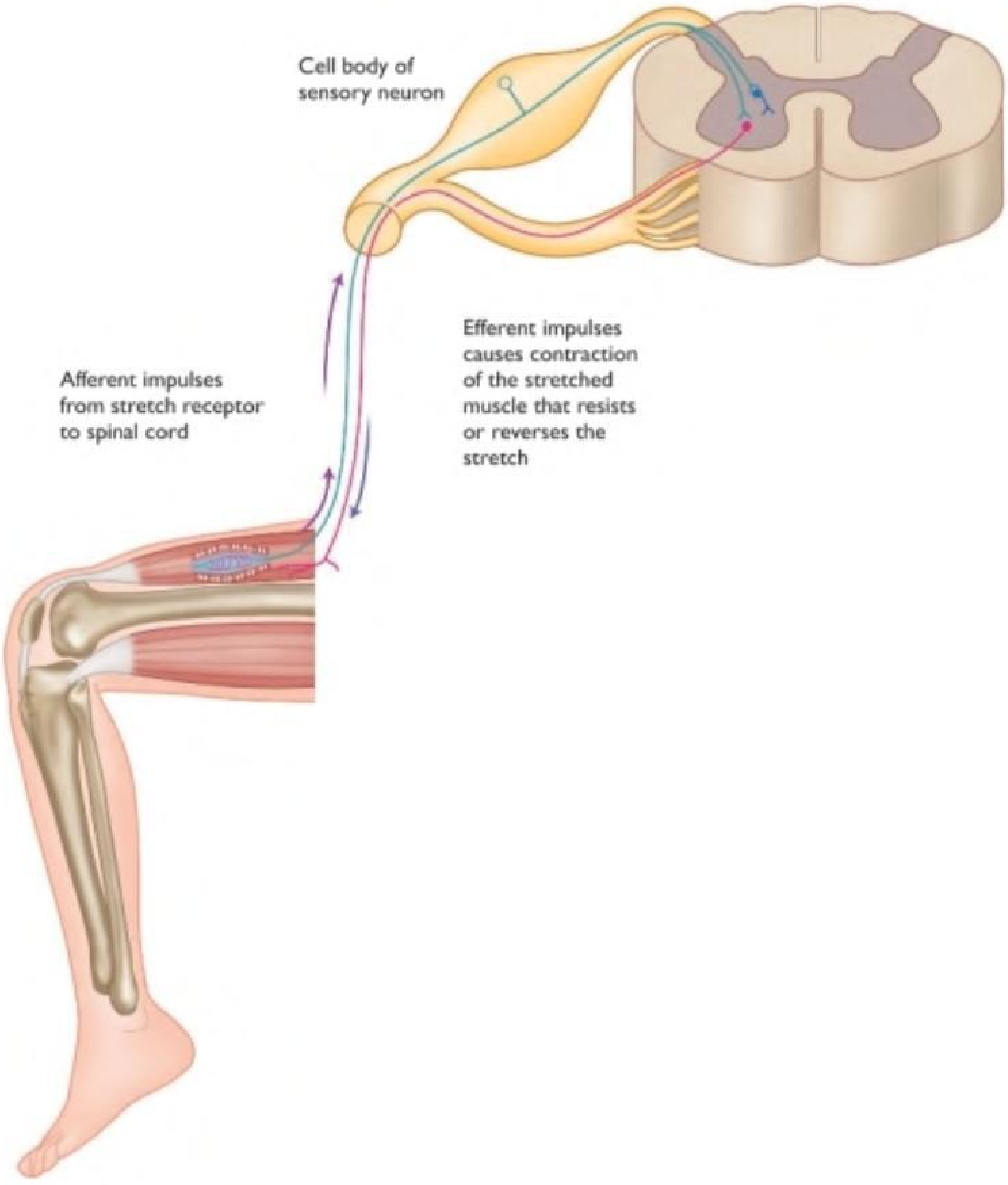


Figure 1.20. The lengthening of the myofascia is sensed by the muscle spindle, which signals the spinal cord. The spinal cord responds with an efferent (motor) nerve signal for the muscle to contract.

The reflex arc creates the contraction of the muscle, which is predominately isometric. Further deceleration of the body's movement then loads the connective tissue, which eventually reaches a point at which the force required to lengthen it farther has been absorbed by the increasing stiffness of the elastic fiber. Once it reaches the point at which the force stretching the fiber equals the tension within it, it begins to recoil, just like a weight bouncing on the end of a spring. The amount of energy lost by the system can depend on the period of time spent at the end of range. This *amortization,* or *transition phase,* will affect the amount of recoil.

Exercise 1.2—Amortization Exercise

These three jumping exercises illustrate the variations and differences in the loading of elastic tissue. Just notice what feels right for your own body, as well as noticing what height you attain with each jump.

***A.* First try jumping without first bringing your head closer to the floor (i.e., don't bend your knees before the jump). This is difficult, as you will only be able to rely on the power of your ankle plantarflexors. Notice how high you are able to get from the floor with just those muscles.**

***B.* Now bend your knees and stay for a moment in the flexed position before jumping. In this jump, you will be able to take advantage of the power of the hip and knee extensors as well as your lower leg muscles.**

***C.* Finally, bend your knees as in *B,* but jump in a flowing movement, coming down farther, into a squat, and then almost immediately pushing up (as you probably wanted to in jump *A*). You will feel the benefit of the additional elastic recoil.**

The jump in *B* added the strong thigh muscles but didn't allow the additional energy of elastic loading, because too much time was spent in the *transition phase.* This is also one of the effects of "museum walking": the stop-and-start nature of it takes away the free energy of the elastic tissue. Rhythm is therefore important, and this can be felt in actions such as jumping and hopping: when done too slowly or too quickly the effort becomes muscular, but somewhere in the middle, the movement will take advantage of elastic recoil and will feel "just right."

That is not to say no muscle energy will be involved, just that the ratio will favor elasticity. And, of course, it will also depend on the activity being done and the person's tissue type, as well as which myofascial areas are being tensioned.

Rhythm will influence the amount of energy we can garner from the fascial tissues (as seen in exercise 1.2). This can vary significantly from person to person and will depend on a variety of factors, including tissue type (loosely or tightly ligamented for example), hydration, age, and the general condition of the tissue. A number of experiments have looked at the reasons why we use different types of movement at different speeds. A walk uses a different strategy from a run, and they both differ from a sprint. Studies of energy usage have found that whenever the movement style is changed to match the speed of movement, there is a recovery of efficiency, that is, less energy is used.

Running at a low speed is less efficient than walking, due to the way the tissues are being loaded. This is probably caused by the increased time in the transition phase, because of the longer stride in running increases downward momentum, forcing the muscles to work to recover. Walking with less upward/downward movement compared to running is only efficient up to 7.25 to 7.4 kilometers per hour, at which speed we tend to change to running (McArdle 2010). The increased speed of the run will utilize the up/down loading into the tissue and the amount of time in the transition phase will be reduced. This has been studied in horses, as they change the style of gait from walk to trot to canter and, finally, to gallop. This gradual increase in speed inevitably leads to an increase in muscle work, but with each gait change, there is a recovery of relative efficiency by taking advantage of more elastic energy being returned from the fascial tissue (Biewener 1998).

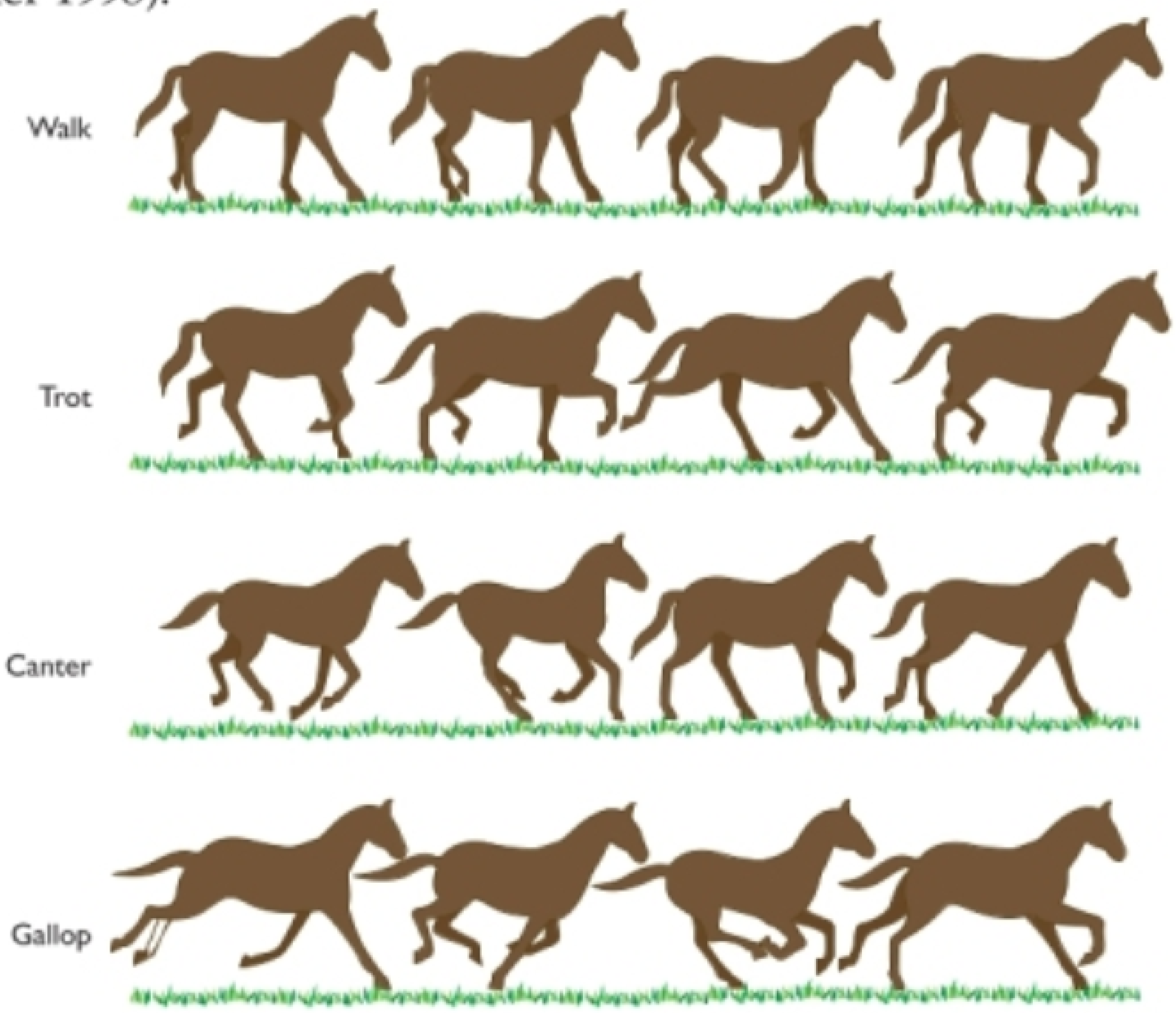


Figure 1.21. Each speed of gait is associated with a different pattern of body use. Changing the length of the stride is one of many strategies to maximize efficiency at each "gear change."

Different movement strategies are used at various speeds to maintain elastic efficiency, but so too must we adapt to other changes in the forces of gravity and ground reaction. Some studies have shown that some African women are able to carry up to 20 percent of their own body weight on their heads and still maintain the same efficiency in walking (Maloiy et al. 1986; McArdle 2010). The analysis of the reasons for this is not fully complete, but it seems that the women are able to transform the increased downward momentum caused by the extra weight into elastic energy rather than muscle effort. We will see how the displacement of body weight can assist elastic loading and recoil throughout the book: vertical displacement predominately loads the Superficial Front and Back Lines, frontal plane movement loads the Lateral Lines, and movement in the transverse plane will affect the Spiral and Functional Lines.

THE STRETCH SHORTENING CYCLE AND WALKING—"EVERY STEP IS A CONTROLLED FALL."

The *stretch shortening cycle* is the basis for many normal human activities, and it utilizes all of the above mechanisms: stretch reflex, elastic recoil, and viscoelasticity. It requires a preparatory movement (or a countermovement) to stimulate the muscle spindles to isometrically contract the muscle, which forces the stretch of the elastic tissues. In walking, this happens through the natural folding of the joints, but in other actions, such as throwing, it is achieved through a countermovement, using the opposite action to load the tissues, often for a movement that will be faster than muscle contraction alone.

Muscle integrity is important, as the muscle must be strong enough to decelerate movement to ensure the fascial tissue is stretched by the momentum. Muscle tendon units do more for the body than simply lengthen and shorten, "they can act as rigid struts to transfer mechanical energy, as a motor to produce mechanical energy, as a damper to dissipate mechanical energy or as a spring to store and return elastic energy" (Sawicki et al. 2009).

All of these roles have to be coordinated. Any loss of elasticity in one area will lead to increased muscle work at another area. For example, imagine losing the ability to plantarflex at push-off, a predominately elastic mechanism. Some other part of the leg would have to compensate for that loss of kinetic energy, most likely a muscle, and that concentric muscle contraction have metabolic costs.

SUMMARY

1. Due to the energy demands of the brain, the human body tries to minimize the amount of calories consumed by muscle work.

2. The development of upright gait freed our hands for other tasks, many of which had calorie-saving or calorie-consuming benefits. This required a number of alterations in our anatomy, which will be outlined in this book.

3. The use of the stretch shortening cycle is our preferred method of motivation in normal everyday movement. The alternative—the constant elongation and shortening of muscles—requires the repeated engagement and release of the actin and myosin elements, which requires a greater use of energy within the body. The stretch shortening cycle eliminates some energy use by taking advantage of three mechanisms: the tissue's viscoelasticity, to begin the deceleration; the stretch reflex, to isometrically contract the muscle tissue; and then the elastic lengthening and recoil of the fascial tissues.

4. Pre-tensioning of myofascial units and elastically loading them through preparatory countermovements adds to the body's mechanical efficiency, decreasing overall metabolic cost as well as increasing the available energy for any single action (such as jumping, as in exercise 1.2).

5. The body has a natural design of myofascial continuities within it, and different movement strategies can incorporate more of them, which will further increase the efficiency of the movement. These "Anatomy Trains" help to disperse force, maximize elastic loading, and use movement of one body segment to facilitate the movement of another.

6. By "triangulating"—using a combination of these lines of force—the body also gains more effective control over movement than it would have if it relied on just one. Incorporating forces from slightly different angles allows for finer control in response to deviating influences.

7. When any part of the body impacts with a surface (most often the foot on the ground), the orientation of the joints serves to send the force of the impact into soft tissue along predictable channels. These channels have presumably adapted over time and serve to spread and absorb the shock; most of them will follow the Anatomy Trains.

8. This predictable order and direction of the folding in the joints then creates the proper conditions to tension the myofascial tissue for greatest economy in their return movement.

Through the rest of the book, I will intermingle elements of comparative anatomy to help visualize the effects of the changes that have occurred in our structure over the course of our evolution. I hope to demonstrate that we need to have a clearer map of the way the body channels kinetic energy and stores it for reuse in the return movement. This first requires an understanding of the events that take place around the joints and bones, and we will then venture into the long myofascial chains that my teacher, Thomas Myers, has referred to as the "Anatomy Trains."