CHAPTER ONE

10 Prestress, or pre-tension, is the quality by which our bodies draw into themselves through the spiralling filamentous development of cellular architecture.

11 Working with the limbs and their rotational origins in yoga is easier when you consider their embryological journey.

12 Limbs emerge from the trunk; the trunk is an interconnection, or continuum of the limbs.

13 Hands and feet can be platforms for standing; fingers and toes are structurally similar.

14 Limb structures broadly reflect one another.

15 For a positional basis of yoga anatomy, we often need something that is less preferential regarding which end is up.

1.1 In the beginning

I first picked up the ***Hatha [Yoga] Pradipika***[2] (HYP) back in the 1990s (widely regarded as the oldest surviving text on Hatha Yoga, compiled by Swami Swatmarama somewhere between the 16th and 15th centuries CE). There was no chance of me taking it seriously – how could a middle-class sophomore raised in 1980s suburban Florida possibly relate to the self-application of a paste made from ash and semen (verse 98)? I was in college when I got the reading list for my 200 Hour YTT. Would I be fashioning a rectal syphon as part of my morning ablutions? What could this possibly have to do with nailing a handstand? One has to laugh, imagining these scenes as the cliché of a yoga-mad generation.

Looking at this juxtaposition of cultures on a grand scale, we find tropes of absurd incongruities as present populations encounter ancient cultural texts filtered through the blogosphere. Yoga's explosion in popularity is impossible to ignore. As ancient yogic practices find their way into the Millennial mindset, cultural appropriation highlights ironies and interpretations from hilarious to hurtful. I wonder what the next generation of young yogis will make of the classical works of yoga such as the HYP and the ***Gheranda Samhita***?[3]

As a teacher, I'm now sitting on the other side of the pedagogical table. I have to laugh (that inward smile of recognition) whenever we start a new 200-hour training at my studio, as I observe keen beginners getting their first glimpse of the *kriyas*. When we turn to the HYP pages, a collective cringe settles over the room: it is easy to understand why. The mood is in stark contrast to the determined focus of the anatomy class – and the divide between them is a chasm, a gap that can perhaps be bridged.

Talking point

Being honest, how many of us "anatomy people" rate the yogic "subtle body" as anything but esoteric oddities of another time and place? Chakras, prana, vayu? Seventy-two thousand rivers of shakti flowing through my nadis. *Hmmm.* Dropping the pretense, those of us that come to yoga as purely physical movement cringe at the concept of the subtle body. Likewise, those whose interest revolves around the subtle body might write off the idea that physical postures are much more than posing. Is there a middle ground?

Across anatomy

What do I mean by subtle body? That is the critical question that usually knocks back methods of empirical research. However, I will offer suggestions based on my journey so far, with a surprising conclusion at the end of Chapter 3. Elements of the subtle body from yogic literature contribute to the telling picture of what is also happening on the level of the gross anatomical structure. It took me a long time to see those distinctions between subtle and gross are just a matter of perspective.

Seeking subtlety, and with the benefit of further experience, I rediscovered the ancient yogic texts, and explored more modern ones. I reviewed a range of Ayurvedic literature,[4–8] inadvertently crashing into fields of soft matter physics, symmetry breaking, architecture, music theory, sacred geometry, and Turing mechanisms. Tubes and spirals seemed to bind it all together. Was there some simplicity here after all?

Somewhat to my surprise, studying Western biomedical anatomy and embryology brought me closer to an appreciation of ancient ideas about the nature of living tissue. What at first seemed to me like super weird (and potentially dangerous) superstitious rites represent what I now see as legitimately insightful human attempts at understanding our place in nature, with due respect for its mysteries.

Through the lens of holism, everything in the natural world is a living microcosm, reflections of the greater cosmic whole. However, conventional anatomical nomenclature reduces our personhood to a box of **levers** and pulleys installed in an isolated fleshy framework of linear relationships. As if our tissues were organized on the inside by a stack of bones – something of an internal scaffold tethering it to uprightness.

FIGURE 1.2

Levers and loads. Drawing from an 1872 physiology textbook demonstrating traditional anatomical lever mechanics: the rigid lever (radius and ulna) pivots about a fulcrum (elbow joint).

(thegraphicsfairy.com)

We are not stacked, literally or symbolically: we remain connected inside and out by webs of different densities, physically and metaphysically. That we still accept the principles of lever mechanics as the basis of all movement – indeed, adhere to them wholesale as facts – to me seems incompatible with the experience of physiological movement. If levers don't define gross anatomy, how could they possibly coordinate the energy-based context of yoga's cosmological anatomy? (Stay with me – we'll come back to the subtle body in Chapter 3).

In this chapter, we unpack the title of this work and explore a selection of body ideas in support of seeing innate anatomical patterns of spirality. These pervade our physiological (and psychosomatic) lives during **embryogenesis** (formation of the embryo after conception – the pre-embryonic stage) and embryonic development (up to eight weeks after fertilization).

CHAPTER ONE

Spiral or helical: what's the difference?

Let's boil it down to basics. The term spiral can be a noun or a verb, and either way it is key to any readership interested in movement. A **helix** is a three-dimensional spiral, often seen in counter-spiraling pairs that form tubes, which are relevant to gross and subtle anatomy. Something that has the shape of the helix is *helical*, or *helicoid*. I use both terms throughout the book, depending on the context.

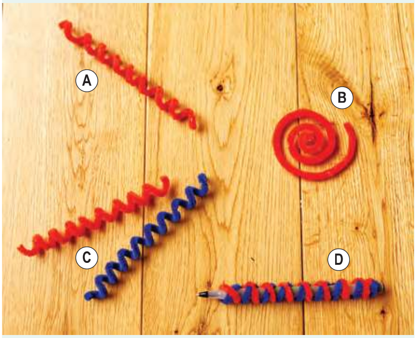


FIGURE 1.3

Spiral and helicoid pipe cleaner models: (A) helix in 3D; (B) 2D spiral; (C) two separate helices of opposite handedness (chiral); (D) a tube formed by pairing chiral helices of opposite handedness.

Here, we will take a closer look at the spiraling embryonic arrival of our limbs into their common configurations to see how our adult movement in yoga plays off these earliest patterns. All threads weave into the fundamental idea that there is value in incorporating spiral anatomy principles into personal and professional practice. Later, we'll see that these spiral principles aren't just the stuff of the gross anatomy: they live at the core of the subtle body anatomy as well.

Key concept 1

To study embryology in the broader context of evolution is to appreciate how things come to be the way they are in the developed anatomical configuration we experience in adulthood.

1.2 Embryology

Embryology is the study of an organism's development in the womb up to the eighth week after conception. The related disciplines of embryology and **histology** (the study of cells and tissues) are usually clustered together in the anatomy department, often in the context of developmental biology. It was only after several years of puzzling over how things got to be arranged as they are in the cadaver that I understood why.

Jaap Van der Wal PhD, MD is a medical doctor (emeritus associate professor) from the Department of Anatomy and Embryology at the University of Maastricht, The Netherlands. He is known as a phenomenological embryologist whose dedication to wholeness in describing the development of the embryo shifts the traditional way in which this subject is generally taught. Van der Wal suggests that the unicellular organism (the living zygote), continuously shape-changes *as a whole*, deploying its self-assembly as an embryo. An author, philosopher, and inspiring presenter, Van der Wal introduced the notion of *transanatomical architecture* into the literature with his tissue-sparing dissection of the human elbow; done in the opposite way to traditional anatomical dissection.[9]

Across anatomy

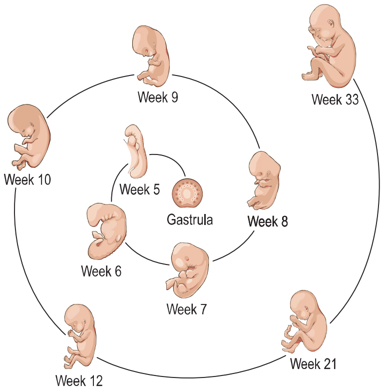


FIGURE 1.4

Human embryo in development.

(apokusay at www.vectorstock.com, with modifications by the author.)

Key concept 2

Van der Wal's term "transanatomical" refers to structure that is trans, or across anatomical structure.

Jaap van der Wal, through the careful and experienced understanding of anatomical dissection and embryological development, offers what many consider to be a maverick view of the human form. His understanding (of both evolutionary history and developmental histology) invites us to find the unique shapes (morphologies) of living bodies, as whole in themselves, at every stage of development.

Joanne Avison

Studying embryology, particularly in this expanding perspective, gives yoga practitioners exceptional insight into functional, postural, living anatomy in asana. Looking at the earliest developmental stages of our bodies means seeing ourselves as stories-in-process-of-unfolding, rather than as a collection of parts that can or can't do specific asanas. With such a big-picture view, we become *trans-asana*. We can thus see our ever-emerging, transanatomical selves as we practice the possibilities of our shape, our unique morphologies, in all their wholeness.

But how do we start and where do we begin? The bursting forth of a limbed creature from a spherical ball of cells is a sophisticated, complex, multidimensional process.[10–14] Studying it involves so much preloaded expertise that the mere prospect of considering embryonic development can be daunting. Take heart; it is well worth persevering with, at the very least, an overview that includes the spiral-bound nature of our formation.

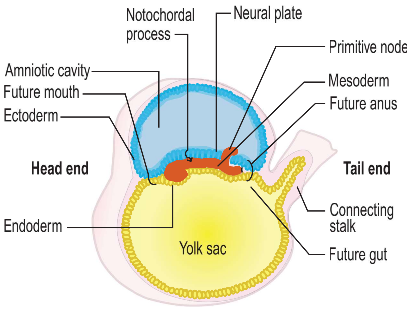


FIGURE 1.5

Gastrulation: sagittal view of the trilaminar embryonic disc around 16 days after fertilization.

One way for beginners to approach the intimidatingly complex story of embryology is to use an analogy. Reckoning with our roundness means visualizing voluminous shapes that are continually in-folding and unfolding themselves. This spiraling pattern, inherent to our forming process, has certain similarities with ribbons winding around a maypole.

The blue whale, the three-toed sloth, and your grandmother, all share the distinction as members of the classification in biology called phylum **Chordata.** That means, at this level, we are defined (among other fundamental features) by the embryonic presence of a **notochord,** a polarized axial structure (meaning one that provides axis) that develops during **gastrulation** (see Fig. 1.5). The notochord becomes the flexible longitudinal axis of this developing pre-embryonic circus.

Gastrulation (after gastro, belly-forming) is the invagination (folding into itself) of the fertilized egg (conceptus, or blastula) into what is classically described as three aspects, known as germ “layers.”

The presence of this axis, in turn, induces the formation of what will become the neural tube in a process called **neurulation** (see Fig. 1.7). *This* tube eventually becomes the central nervous system. In a process something like structuring a maypole, the notochord provides a kind of mast during embryological development. It generates the metameric array of vertebrae, around which other tissue elements self-organize in species-specific ways, waves, and whorls. Whether water-bound, earth-bound or upright, the tissue ribbons all dance around the notochordal guide-pole.

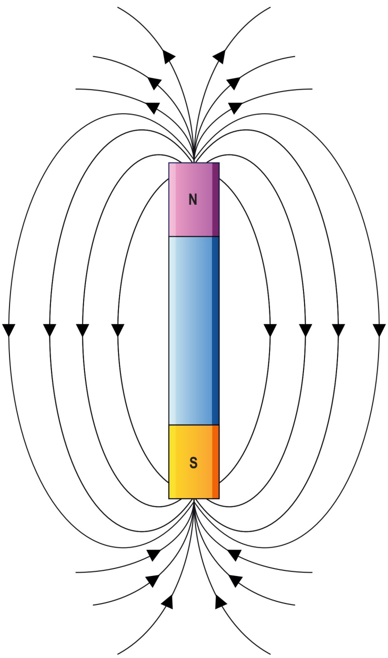
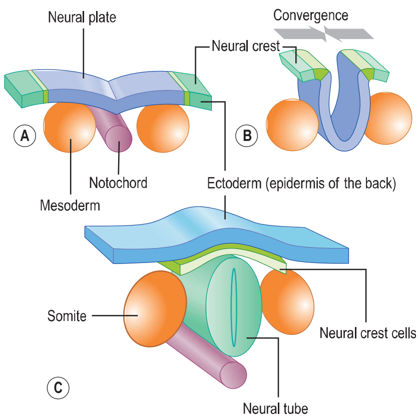


FIGURE 1.6

Vertebrate eggs are polar structures like the example shown here of north and south. In the embryo, the two opposite poles are differentiated as animal pole and vegetal pole. Polarity is an electromagnetic phenomenon, and it is the basis for the earliest orientations of the embryo that determine everything that comes next in development. The axis passing through the embryo is known as the animal-vegetal axis. Polarity is normally expressed in the egg as a gradient in the ratio of cytoplasm and yolk from animal to vegetal pole.

The notochord later becomes a somewhat different player in the developmental dance. After serving as the central theme around which the *whole spine* dances into being, the notochord becomes the nucleus pulposus (NP, inner gel substance) of the individual, intervertebral discs. Traces of the notochord persist into early adolescence, and there is enquiry around pathogenesis related to replacement of the notochordal remnants with **chondrocytes** in the maturing child.[15,16]

> Suffice to say, nothing is redundant, and it is worth considering from a shaping/balancing body point of view, that the more global embryonic notochord (a so-called transient structure of the embryo) becomes a local notochordal echo in each disc. Together, the discs act as spacers; organizing the spine *as a tube* of sorts. Each disc retains an NP, and our movements could be said to join the dots when we integrate spinal motion well, at the gross level of asana practice.
>
> **Joanne Avison**



Key concept 3

The notochord offers an attachment site or guiding central theme to developing tissues and a role in our development beyond the embryo.

1.3 The meso story

Soon after you embedded yourself into the uterine wall of your mother, you went through this most important transition of your life: gastrulation. Forget adolescence, university, marriage, children: by far the most significant moment of your life was when you became a trilaminar disc. Sometime after compaction of your first cells, but before you grew limb buds, you transformed yourself from a hollow ball of cells into a double bubble. One bubble became a cavity containing amniotic fluid (the amniotic sac), your personal ocean that you instinctively wrapped around yourself. The other bubble was to be your yolk sac (this process of gastrulation is hungry work; you instinctively enveloped your yolk sac too).

FIGURE 1.7

Neurulation: the folding "burrito". (A) Coronal view of the notochord in situ; (B) notochord signals induce tubification of ectoderm at the neural plate as shown through Day 18; (C) the ends of the neural plate fuse to form the autonomous neural tube with neural crest cells visible by Day 23.

The two surfaces of the joined bubbles are then known as a two-layered oval, or the bilaminar disc, in classical terminology. Amid some jostling between the upper and lower floors, there suddenly appeared an in-between, composed of eager cells that migrated from the ground floor into the basement down a spiral staircase between them. They poured downstairs as a crowd, in response to different growth rates and patterns. These highly responsive cells found themselves forming this 'tween tissue, a kind of mezzanine, known classically as the **mesoderm**, or middle layer. This now *tri*-laminar disc whorls, folds and enfolds itself into nested tubes, and from here a whole new level of tubular partying exudes from this early patterning.

FIGURE 1.8

Brightfield photomicrograph of chick (*Gallus gallus domesticus*) embryo development at 60 hours; 29–32 somites.

(Scenics & Science/Alamy Stock Photo)

This so-called mesoderm (that Van der Wal calls the *meso:* he emphatically demonstrates it is not a "derm", bearing little or no resemblance to a layer),[17] is comprised of a primitive field of fluid and **protein**. This field is an embryological juice called **mesenchyme**, a soupy spectrum of loose fibers suspended within a mucous **ground substance**. This juice is worth the squeeze; from it, we derive the tissues of locomotion and circulation. The urogenital systems also arise from within (and around) this juicy milieu. They appear according to the species-specific plan that orchestrates the chrono-structural origami of your unique architecture.

FIGURE 1.9

Frontispiece of Vesalius' *De Humani Corporis Fabrica* (1543).

From this same soft start, the **lymphatic** and **circulatory systems** emerged, which (along with the nerves) were later intimately woven around the maypole of your body plan. The tirelessly winding **somites** led this part of the dance, bent on rotating to become the fabric of your torso, arms, and legs. These rapidly differentiated on their journey towards their more familiar final configurations.[18]

In an average anatomy lesson since the time of **Vesalius** (see Fig. 1.9), one would likely learn that this preceded the fully developed human body: ultimately composed of approximately 206 bones and 640 muscles. Unlike your average anatomy lesson, in this chapter we will stop seeing the developed body as a parts list of separate structures and separable layers. Here, rotation and invagination never come to a definitive end.

Key concept 4

Meso is the middle tissue that relentlessly orchestrates, connects, supports, and defines the bodily structure.

Instead, we will start from the embryological soup and decline to separate it into three layers. Since all the membranes are swimming in their respective sub-soups, they contain and are contained by the fluid body that continuously emerges through itself. The body is relentlessly subtle. It is composed of a continuous, collagenous, spiraling, semi-conducting liquid-crystal arrangement of tubular structures arising from a primitive stew (gelled in **bound water** like a gelatin dessert).

Memorizing all the detailed embryological strata presents the same trap as memorizing the yet-to-become 206 bones and 640 muscles designated to the developed human body. I'm inviting us to reframe yoga anatomy to allow for the notion that the in-between spaces (which are not empty) incorporate something much more usefully considered as the fluid-fascial matrix we all embody.[19] In real life (and living motion) the mesenchymal milieu of the embryo doesn't really disappear, despite what labels we assign to its final structures.

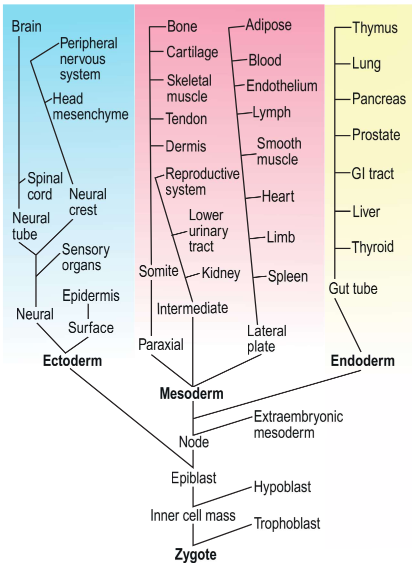


FIGURE 1.10

Fields of development: ontological tree showing the gist of the germs/derms. In embryology infographics, the usual color code is as shown: blue is ectoderm, yellow is endoderm, and red is mesoderm.

Classically, post-neonate, the cell and that which surrounds it factor separately. That is, what surrounds the cell is more generally referred to as the **extracellular matrix (ECM)**, meaning "outside" the cells. Recent research is following the same pathway to wholeness we all seek (at least philosophically). Pathologists Neil Theise and Rebecca Wells (and colleagues)[20] have suggested the term *interstitium*, to encompass the nature and structure of the internal tissues.

This tissue field comprises a continuum, containing virtual spaces and fluidity classed as fascia in the literature,[21] and always expressing as filamentous variations on a soft-matter theme. As such, the body is a spectrum of thicknesses, folding, unfolding and in-folding, imbuing and self-organizing to form its own pockets and tubes within pouches and pipes, to become itself. Howsoever you cut it – it begins and remains one piece.

Key concept 5

Thinking of the embryo in terms of distinct germ layers with definitive fates hides some of the more enlightening plot twists in the story of our spiral-bound tissues.

Meso and the layerless cake

This inner world of the *meso* derives from the embryological region between the ectoderm (upper or outer layer) and endoderm (innermost layer). Classically known as the mesoderm, or middle layer, this inner-middle world generates fields of muscular tissue that develop into what is generally referred to as the musculoskeletal system and its attendant fasciae.[9]

This layer, or derm, is not a layer in the strict sense. Instead, it is a specialization of cells that I'll refer to here as meso, and later as the ***mamsa*** (the Ayurvedic anatomical equivalent that is also all-encompassing). Factor in the **multipotent** neural crest cells (NCC) that feature in peripheral innovation and contribute to the locomotor system as well, and it becomes clear that pinning down the development of these tissues to any one term is just not congruent with what happens in real life. (See "Head, shoulders, knees and toes" below for more on neural crest cells.)

In her book, Avison introduces another applicable term, alongside the classical specialization that refers to the differentiation of these structures. Tissue formation is a process of instinctively knowing what to become and becoming – this is what Avison calls the "pre-formance", and van der Wal calls the "performance" of creating ourselves as living volumes.[22] Whatever you call it, development cannot be entirely explained by genetic, chemical interactions: we push and pull ourselves into being[23,24] as mechanical forces (tension and compression) act in continuity.[25–27] It is a self-perpetuating process.

Donald Ingber was among the first to use the term **mechanotransduction** as the structural/action-based foundation of **tensegrity** and gene expression.[28] Closely reflecting a key component in the study of yoga, Avison describes the process of *spacialization* that the meso, notochord and somites undergo as the kinetic organization of the form. Genetic signaling, polarity, impulses, fluids, and fabric folds prompt that process – as they, in turn, sculpt the very same flows and folds they call into placement.

1.4 Mighty somites

During the earliest stages of embryological development, the neural tube wraps itself up like the folding of a burrito. As this innermost inner-tube forms (in response to the notochord), it zips itself up to create a tube that induces the formation of still more tubes. Much tubification occurs in parallel with the notochord, animating pairs of cells that run along the length of the forming neural tube, from head to tail end. These pairs give rise to polarized somites (from *soma*, or body), and their path is a bit like the ribbons weaving around the maypole, from the top down.

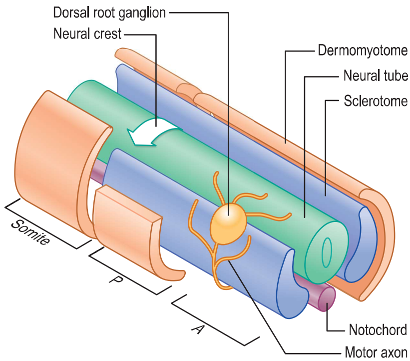


FIGURE 1.11

This diagram of the anatomy of spinal nerve segmentation shows the early elements of the developing peripheral nervous system including the migrating neural crest cells and outgrowing motor and sensory axons. These are shown with reference to the somite derivatives (dermomyotome and sclerotome). Most of the dermomyotome has been peeled back from the somite on the left, revealing the sclerotome as subdivided into anterior (A) and posterior (P) aspects.

(Redrawn from Kelly Kuan CY, Tannahill D, Cook GMW, Keynes RJ. Somite polarity and segmental patterning of the peripheral nervous system. Mechanisms of Development. 2004;121(9):1055–68.)

The "little bodies" of these somites arise as spheres from the mesenchymal paraxial mesoderm in a regular, rhythmical sequence. They migrate along the head to tail axis (anterior-posterior, cranio-caudal axis) as pairs of epithelial balls, forming the body-tube of the whole torso (see Fig. 1.7). Somitogenesis, the origin of somites, is driven by a clock and wavefront mechanism[29] that transforms the somites, one on each side of the developing neural tube, into sets of more differentiated tissues.

The spheres further subdivide as the animating structures of potential muscle, bone and connective tissues (termed **dermomyotomes**, **sclerotomes** and **syndetome**/**fasciatomes**),[30] placed and spaced by polarity[31] toward their transforming position. The **ventromedial** portion of the somite becomes mesenchymal sclerotome (together with the midline notochord) which, with increasing maturity, differentiates into the ribs and spine. The spine is destined to encase the neural tube (early central nervous system), a tube-within-a-tube around which the tubular torso is simultaneously choreographing a burrito ballet of its own.

Key concept 6

Dermatomes show us how our surfaces arrived as a result of early tissue wrapping around a central axis (notochord). The innervation patterns of these surfaces reveal how branches of the nervous system hitched a ride on these tissues during embryological development.

The **dorsolateral** (front/back) portion of the somite becomes the dermomyotome, fated to become the axial dermis from the dermatome portion, and skeletal muscles from the myotome aspect.[32] A further subdivision emerges between

Dermatomes

Dermatomes are perhaps the most famous of the somitic subdivisions as they track the story of development. The somites form whorls that abseil around (like ribbons dancing around the maypole from top to bottom), taking with them the nascent neural tissue expressed into the **dermatomes** as seen in Fig. 1.12. Dermatomes derive from the embryonic outer layer (ectoderm) from which the skin and subcutaneous tissues also develop. These become the areas of skin supplied by the branches of a deeper aspect of the central nervous system (known classically as single dorsal root ganglia). Essentially, they give us a map that illustrates the journey of the inside becoming the outside.

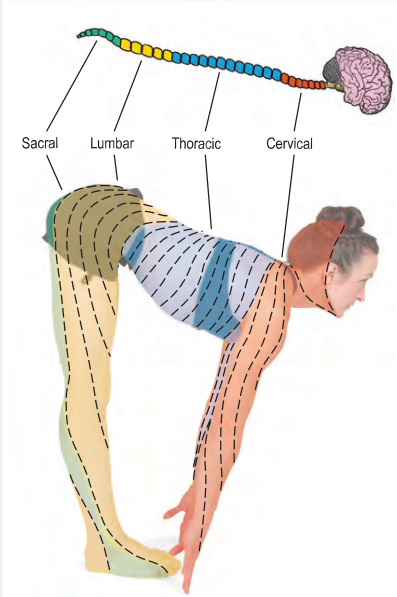


FIGURE 1.12

Dermatomes: the nerves originating from the neural plate take a circuitous route, hitching a ride along with the myotomes and sclerotomes to reach their final destinations as shown.

the myotomes and sclerotomes; this, the *syndetome*, is destined to become the tendinous tissues of the segmental muscles attaching to the vertebral array.

Although this is metaphorical and the somites don't literally go on to wrap repeatedly around the notochord, the tissue streams they initiate *do* weave around the trunk, arms and legs. It is illustrative of the spiraling nature of embryonic development. Once the axis establishes itself, our proto-tissues wrap around the longitudinal tubes ventrally and dorsally. Somites are the whorled organizers of the body plan.[33] They define the spine to create another set of tubes: the belly cavity ventrally and the cavity for the central nervous system along the inner dorsal contour.

Appreciating the transformative wrapping, it becomes easier to see how our compartments wind and twirl around the inner tubes. These, with use and time (and under the influence of differential growth rates and force transmission through the body), will eventually become articulated bones. Even the bony arrangements are evidence of this deep, spiral strategy. How our limbs rotate into position embryologically is a crucial feature of this chapter, setting the stage for a focus on the rotational nature of the limb patterns as they develop.

Head, shoulders, knees and toes

As far as Earthlings go, to say that the vertebrates are evidence of a successful strategy would be a monumental understatement. To develop the predatory lifestyle needed to carry out world domination, organisms required a head. It turns out that having a head is structurally and functionally critical. So complex was the task of generating head structures that an extraordinary type of vertebrate cell population emerged to carry out the process: thus evolved the neural crest cells (NCC) (see Fig. 1.7).

Often regarded as the fourth germ layer, the NCC form in the neural primordium of vertebrate embryos.[34] This structure arises in conjunction with the other architectural derms and contributes to nearly all tissues and organ systems throughout the body.[35] The craniofacial skeleton (referring to the head and face – not the fascia as such), the peripheral nervous system, and pigment cells are among the many tissues that arise from NCC.[36]

The NCC not only give rise to our skin color (i.e. pigment-producing cells called melanocytes), peripheral nerves and their ganglia, but also to a variety of connective tissues, bones and cartilages of the head, known as **mesenchymal** derivatives. In other regions of the body, these tissues are described as mesoderm-derived, meaning they arise from between the ectoderm and endoderm (i.e. from the meso according to van der Wal).

In reality, however, the so-called derms are not distinct, or separate or layered. The literature tells the story of what makes vertebrates truly unique embryonically, and of course, it scales up to our adult configurations.[37] It is well-accepted that NCC persist into adulthood and form a reservoir of stem cells with therapeutic potential.[38] It transpires that NCC aren't just multipotent and pervasive, they also yield surprising interconnectivity throughout the entire body from the earliest stages.

Key concept 7

Even though we use the term layers for convenience, bear in mind, as we traverse the basics of classical embryology, that this transanatomical architecture isn't separate anywhere, ever.

What all that means in plain English is: these highly **potent**, original cells of the embryo form our color on the outside, our gut, nerves and connective tissue system on the inside (which are unpigmented; we are all the same on the inside), and they give rise to a great deal of what connects them in between. This suggests that separating the body into classical classifications (just as separating humans beings based on color) is missing a very significant point. Essentially, this points to a layerless, in-the-round reality in which the derms are NOT as distinct as we might wish them to be in advance of an embryology exam.[39,40] Keep this in mind as we traverse the layered terrain of basic embryology.

Talking point

Yoga is rapidly expanding as a transnational, trans lineage practice. Do we need to expand our ideas of anatomy for yoga to encompass the bigger picture and consider the transanatomical nature of our living architecture?

1.5 Out on a limb

The activity of living things is primarily dictated by which element they navigate with their limbs, be it the sky with wings, the land on legs, or swimming in the water with fins. Vertebrates, in general, tend to be characterized by their limbs: they fly in the sky, knuckle-drag, pronk, paddle, prance, pose, and run marathons. In humans, the trunk contains the organs responsible for immediate survival, but it is our limbs that define us as bipedal quadrupeds (from a structural point of view).

> These definitions arise from the forces those limbs negotiate in motion, which also generate the patterns of this soft matter we each self-assemble. The pattern of matter is the essence of this species-specific, environment-dependent, space-time configuration we call form or structure, which, in turn, defines the species and the forces it can negotiate. Every maypole begins in 360 degrees of whatever it calls home (earth, air or water). This matters, as we understand the relentlessly spiral patterns in which our soft matter architecture is bound.
>
> **Joanne Avison**

Dr Stephen Levin, originator of the term "bio-tensegrity" – a blend of biology and tensegrity, describes the spine as a tensegrity truss system[41] (we will come back to Dr Levin and biotensegrity in Appendix A). The truss model necessarily includes the whole body; extending it to the limbs, we can incorporate it to understand the body *as a whole*. These trusses are modular body segments that have an aspect of **chirality,** or handedness, with **constraints** that we pair in both flow and opposition in asana.

FIGURE 1.13

The body is entirely composed of soft matter, even the bones. In this simple learning activity, you can soak a bone in vinegar for some time and feel for yourself how the bone crystals dissolve, leaving the bendy fascia behind. Living in the countryside, we often find a bony specimen while out walking. I took the opportunity to use a pair of rabbit scapulae for this demonstration.

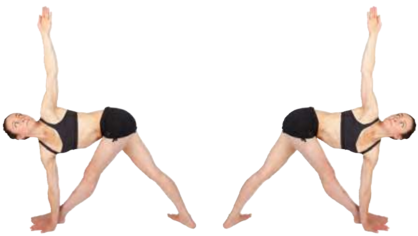


FIGURE 1.14

Yoga postures are often chiral, as pictured here in Parivrtta Trikonasana

(Demonstrated by Sarah Hatcher)

Chirality leads body elements to twist in a particular direction. Arms rotate inwardly when we ground them downwards and unfold externally when we reach out into the world. Legs have a similar rhythm, literally configured in rotation. In truth, the appendages are not appended to the trunk at all. Instead, you can think of them emerging from the axial body compartment as extensions of the spiral (helical) tracks of the trunk.

> Chirality refers to mirror-image pairs of objects that cannot be superimposed onto one another. To find a great example, just look down. Your two feet are identical and opposing shapes. Chiral things tend to appear as a complete pair with a function greater than the sum of the individual parts. Together they facilitate our gait motion through rotational correspondence. This is a fundamental clue to understanding non-linear biologic forms and the keystone of this book.

Limbs unfurling

It is hard to imagine that we all begin life as a single (if charmed) cell, a fertilized egg made up of both its mother's and father's genetic material, uniting their respective DNA. As Avison points out, "acorns don't go to acorn school to learn how to become oak trees." We have all that we require to become us baked into the ingredients at the outset. The being precedes the body, so-to-speak, and once that loaf is baked, it cannot be unbaked or reduced to parts.

That unicellular sphere soon becomes multicellular (the one becomes the many). They go on to differentiate (specialize and spatialize), enfolding and curling eventually into a flexible and flexed trunk. Our limbs come later to the party: only after four weeks, relatively late in the process after the foundational body plan has formed, do our limb buds appear.

FIGURE 1.15

A supine twist is formed as gravity stabilises the opposing pairs of limb trusses.

(Demonstrated by Fadzai Mwakutuya)

Exquisitely intricate molecular choreography regulates limb development in vertebrates like us. The chemistry of the limb dance is much the same across species and, as it turns out, the recipe for baking limbs is also very similar across species.[42,43] Limbs develop as outpouchings of mesenchymal cells. These pouches of goo undergo tremendous shape changes (or morphological transformation), that give rise to different thicknesses of the tissues in different places, such as the cartilage "condensations".[42,44,45] Such condensations are the fundamental cellular beginnings of our manifesting morphology.[46]

What we now experience as our bones are such cartilaginous (fascial) elements, pimped out with bone-forming minerals that we pinched from maternal reserves (typical). These we reorganized as we self-assembled and found our forms ever-informed by the original recipe of our blueprint, and reinforced by the particular ways our species interacts with earthly constraints. Bone formation occurs much later in development and continues post-neonate; however, the pathways are writ large in these embryonic condensations.

Key concept 8

Embryology shows how the limbs rotated out of their original limb buds into their recognizable forms as arms and legs, emerging from the tissue and in continuity with it.

The sophistication of this process genetically stands outside the scope of this book. For understanding how movement patterns appear in the limbs, it is enough to know that limb development begins as the tiny buds emerge through the body wall. The complexity of the somite choreography initiates a longer axis in each. These arise as condensed inner-tube tissues that trigger the dance into formation.[47] The various tissues have different growth rates, which (besides the complexities of a heart-led patterning for the circulation with which to grow) keeps our maypole theme, continuous within each limb.

The central pole is analogous with the core cartilage that bolts, piston-like, through the middle. The ribbons are the other limb tissues, wrapping around the pole – but pulled under tension into form by the inner-tube, as they grow at a slower rate and get pulled into their pre-tensioned architecture. As these limb sproutings continue, their journey takes them inevitably along a gently twisting path into recognizable arms and legs.

The far (distal) ends of the limb buds, most distant from the spine, spread out to form handplates and footplates before they differentiate into fingers and toes by about week six. The finger-forming process involves as much editing as it does the production of a new structure, another layer of the morphology process that reminds us of the importance of negative space.

Limb development

- Upper limb buds are visible by days 26–27.
- Lower limb buds are visible by days 28–29.
- Upper limb buds develop along the lower neck (inferior cervical) segments.
- Lower limb buds develop along the lower torso (inferior lumbar) and upper tail (superior sacral) segments.
- Each bud forms a specialized ridge that guides the growth and development of that limb.
- Each pair of limbs rotates around the body axis.

- Each pair of limbs experiences differential growth rates that cause them to curl around their axis.
- Around week six, the handplates and footplates begin to differentiate by spatializing the digits.
- Limbs are structurally established by the eighth week of development, by which time they have digits (fingers and toes).

FIGURE 1.16

Human embryo, six weeks. The black circle is the edge of the fundus of the eye. Visible here is the umbilical cord, a strand of tissue containing the two spiraling arteries that carry blood to the placenta (the organ embedded in the uterine wall that interfaces maternal and fetal circulations) plus one vein with return supply to the fetus.

(Lennart Nilsson, TT/Science Photo Library)

Out of the flatness of fishes

Evolutionarily speaking, our limb patterns come from those of primitive fishes.[48,49] As the planet's atmosphere changed, life took to the land, and gravity was experienced very differently by those creatures that emerged from the buoyancy of saltwater. Limbs, initially flat fins, evolved rotatory shoulder and pelvic joints as a direct result of navigating over slippery muddy flats and mounds, and the need to lift the head to see the emerging view. Imagine the change in perspective as the once-uniplanar perspective scaled up and around into 360 degrees!

It was imperative to develop the ability to look up (push up from the ground) and see around to where the body could go, all while navigating slithery surfaces to push upon, pulling along the rest of the gravity-bound body. This evo-devo (evolutionary development) dance was led by the instinct to move forward and, later, to look up. Further rotation at the elbows would follow, as part of this ongoing evolutionary process toward *orthograde* (walking upright with limbs swinging independently) posture. Given what we have developed into, this was essential.

The legs of land-walking bipeds eventually needed some kind of jointing at the knees to organize the seeing, moving body relative to the earth. Further, they needed to move even more efficiently over land while navigating with agility around who or what might be in their way. We, humans, continue to experience changes in our strategy, particularly noticeable in how the elbows and knees bend in opposite directions. In humans, the arm buds develop earlier than the leg buds emerge and continue their advantage throughout gestation.

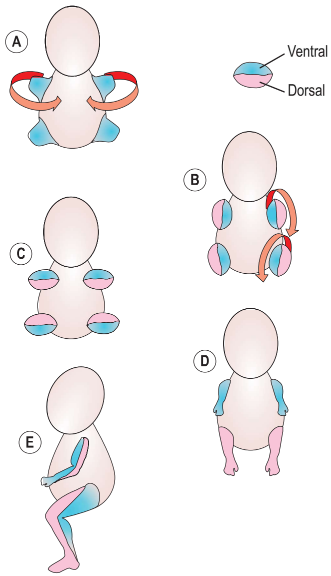


FIGURE 1.17

Ventral-dorsal rotation.

A We start out as a belly-up turtle with our four limb buds directed laterally

B Rotation of the limbs around to the front of the body brings the limbs out of the coronal and into to the parasagittal plane (to the front)

C The limbs continue to spiral around their long axis: upper limb externally, lower limb internally. The dorsal surfaces of the limbs are then facing each other as the limb buds continue to develop.

D As the limbs mature into their adult position, the tissue that started out in the ventral is now anterior in the upper limb, but posterior in the lower limb.

E Looking at the adult from the side, with bent knees and elbows, the ventral surfaces are the flexors.

During the seventh week of gestation, we see the limbs spiraling into place. The arms slide down from the neck as they emerge from the sides as limb buds emerge and rotate ventrally. Their ventral surfaces rotate upwardly (laterally/externally), offering the medial arm and palmar surface of the hand upward, evident in the carrying angle of the elbow. The legs rotate inwardly (medially/internally), taking the medial aspect of the limb bud into a dorsal position distally (what was the ventral lower limb, becomes the back of the lower legs and soles of the feet). These leg rotations lay the tracks for future knees and their so-called screw-home mechanism.

These significant turnings take tissue along for the ride, bringing the body elements of the arms and legs into a future readiness for the **anatomical position** (see Section 1.7). In this position, the elbows point toward the back (dorsally) and thumbs seek a lateral home (pointing out to the sides). Likewise, we see the knees take their place on the front surface of the body (ventrally), and the big toes coming together into their position we know so well from looking down at our feet on the mat.

At the eighth week of development, the embryo is approximately 23 mm long. By this time, the hands stretch through the **inchoate** arms and continue to reach through, as an echo of something you might feel when pulling on a latex glove. The cartilaginous precursor of the yet-to-be bone grows many times faster than the surrounding tissues, spiraling into form.[50]

Elbows and knees arise as the different bands of tissue grow at different rates, like pea tendrils wrapping around their trellis, or ribbons around the maypole of their yet-to-become bony inner-tubes. The process is spatiotemporal sculpture.[51] The self-sculpting tissues of the embryo require both fluid-like and solid-like states to deploy themselves into wholeness.[52]

Key concept 9

Between weeks five and eight, the limb buds elongate and spiral into and out of the positions characteristic of the newborn.

From these somewhat undignified-looking beginnings, with our developing limbs poking out furtively from the still-tailed body wall, the buds spiral their way into a more advantageous position and differentiate to allow us a reasonable means of interacting with the world. The action happens through the balance of chirality (the counter-spiraling essence of our forming formula). The limbs extend from the trunk and converge through the trunk. In yoga, it becomes increasingly apparent that the limbs connect us to the earth, the sky, each other, and into ourselves, hugging these original patterns to us, to transcribe forces of the dance into form.

Tuned into tension

At this point in the story, we need to recognize that we are prestressed from the outset. Let's expand on what **prestress**, or pre-tension, means. When you put a tent pole into a tent, it has to be ever so slightly longer than the pocket housing it. This relationship allows the canvas to be held open and upright (between the tent poles of the whole structure). Thus, it contains a volume, essentially tensioned by the compressive forces of the rods (which are compressed by the tensional forces of the tent fabric). It is the reciprocal balance between these two forces that creates and maintains the shape or volume of the structure. The third force is the result of the particular combination of the other two.

FIGURE 1.18

Nakrāsana (Crocodile pose). Cellular prestress (self-stress) in the structural matrix is what gives our bodies the stiffness and elasticity to bounce high after greeting the ground.

(Demonstrated by Emma Isokivi)

Unlike us, a tent has to be tethered to the ground to find its shape. Nevertheless, it is classed as a tension-compression based architecture, and the canvas or fabric has to be under tension to hold its shape. We are born with that pre-tension (or prestress) in place as a result of our bones growing faster than the surrounding tissues, within the limb tubes. In other words, our muscles and tendons and nerves and tissues are all pulled into shape embryonically. Some evidence of this is that we naturally curl into the fetal position, our hands and feet rest in slightly arched shapes, and our undone posture default is curved and folded.

Think child's pose. That is our prestressed pattern, dyed in the wool before the forces of life bring our bones into the more adult expression. Our bones become something like the tent poles in the example of the tent, even though in the embryo, they are not yet fully formed. The bony precursors, however, prestress the architecture in differential growth patterns as closed couplings formed in concert with the surrounding tissues.

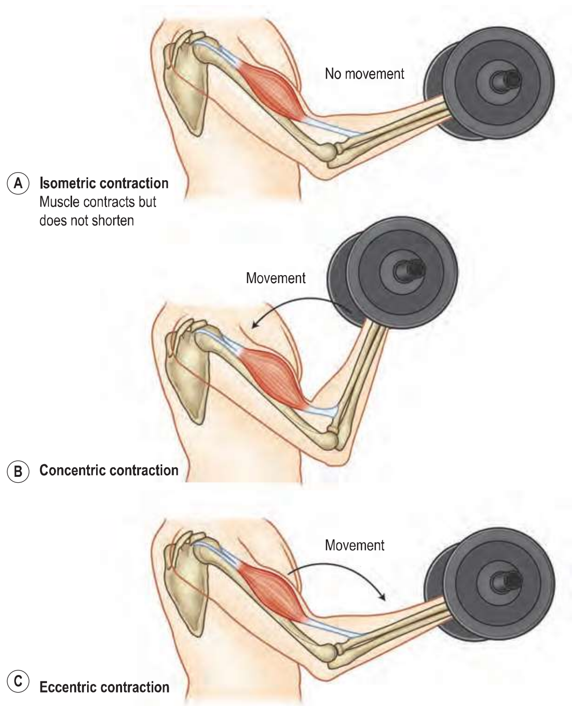


FIGURE 1.19

The classical explanation of musculoskeletal movement is based on a model of simple levers in which a discrete muscle acts on a joint to pull one bone toward another in a single plane.

Key concept 10

Prestress, or pre-tension, is the quality by which our bodies draw into themselves through the spiral development of cellular architecture.

Biologists have shown that not only is the prestress reinforcement strategy found in the cell, but it is also a global feature of all organisms[53] (explored further in the online chapter, Reflection and growth – see p. xii for access details). Danièle-Claude Martin describes one influence of prestress in functional movement in her book when she refers to the phenomenon as "comfort self-stress."[54] It is "self-stress" in the sense that no outside forces are doing it to us. As such, the structure of the organism itself provides the internal pattern of couplings, which is reflected in the weave of the prestressed architecture.

An invitation

For a lively conversation between anatomy and yoga, let's consider the entire organism. Not just as it is now, but as it has been since conception, as it may have been evolutionary eons ago, and where this trajectory is likely taking us into the future. As yogis, we are genuinely interested in the body regarding its entire timeline, not just the isolated components of a reductionist or mechanistic view. That view is the box we have inherited and the one into which we are trying to cram our understanding. Because it doesn't fit as such is why we benefit from unboxing anatomy to see it integrated with the bigger picture.

I invite you to consider a new way of envisaging those adult human arms and legs, as we have become used to calling them. We draw them as sticks on a stick figure; work them out on a quad press in the gym and talk about "flexing the knee" and "extending the elbow" as if they ever do that at right-angles. Consider now that their journey, entirely emerging through a process of fluidic, pretensioned rotation, cannot make sense if we attempt to attribute their motion entirely to a **lever model** and bending moments at the joints.

Key concept 11

Working with the limbs and their rotational origins in yoga is easier when you consider their embryological journey.

Moreover, how could a lever model (see Fig. 1.19), that by definition can only move in one plane, describe the motion we experience? How does it make sense that one muscle could move independently and to the exclusion of others, when we know from the lightest consideration of the embryology that the entire process is orchestrated as a whole, at once, by the time the whole body is the size of a walnut? Let's take a more in-depth look at how these limbs relate to the trunk invariably in *continuities* that are *always* influencing the rest of the system from which they emerge.

1.6 Legacy of limb symmetry

The limbs take root posteriorly in the torso tube, or the thoracolumbar region (see Figs 1.20 and 2.36). They emerge from and converge into a dynamic cross-ply that weaves into deep fibers and sheaths around what will become the abdomen, diaphragm and pelvis; all made of fascial pockets, self-assembling from the folding and unfolding process we have described. That includes the internal sheath of the diaphragm and the fascia that wraps and encompasses the posterior abdominal wall, forming the structures known as the endopelvic fasciae en route.

> This is another challenge of continuity, connectivity and chirality. Everything arises from this unicellular beginning; using the connective (and connecting) tissue template, from which it self-assembles and forms. There is only one continuum: nothing is added or bolted on that doesn't emerge from the original structure. This entirely undermines the most basic notion of levers (open two-bar chains – what is open?) and goes further to suggest that the fascia is the fabric of the unicellular architecture that becomes the multicellular architecture that there is only ever one of! You are one, containing the all as a continuum. Even the cells are made of it; so that the torso tube is part of the whole weave. The ONE wholeness; the one fascia – in all its paradoxical variations.
>
> **Joanne Avison**

Discrete limb boundaries do not exist in a seamless model. The smaller bones and joints integrate as part of the continuum of tissue, deploying even before they have had sufficient forces put through them to become bony as such.[41] Research in limb disparity (long legs, short arms) in

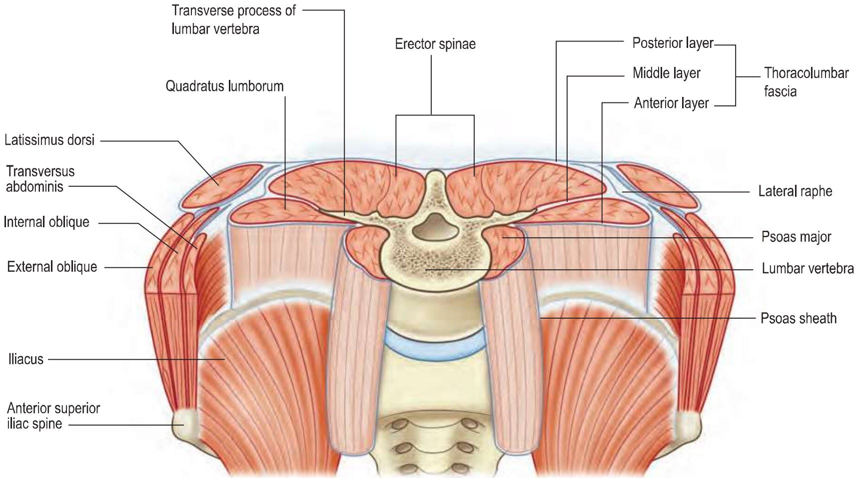


FIGURE 1.20

The thoracolumbar fascia includes the deep fascial compartments of the limb trusses woven through the X of the lumbosacrum from superficial to deep, extending to contain the psoas in continuity with the diaphragm and peritoneal cavity within.

Table 1.1 Comparison of a basic selection of anatomically allied parts in the upper and lower limbs

	Upper limb	Lower limb
Soft tissue	Pectorals	Hip flexors
	Latissimus dorsi	Tensor fasciae latae/gluteals
	Deltoids	Gluteals
	Rotator cuff	Deep 6
	Biceps brachii	Biceps femoris
	Triceps	Quadriceps
	Anterior compartment of forearm	Posterior compartment of lower leg
	Palmar surface of the hand	Plantar surface of the foot
Skeletal elements	Scapula	Hip bone
	Humerus	Femur
	Olecranon	Patella
	Radius/ulna	Tibia/fibula
	Thumb (pollex)	Great toe (hallux)

humans, when compared to other primates, shows that development continues to shape evolutionary change.[55] We point to the whole story, not just a retrospective view of development, but also a full picture including that of potential future scenarios.

Key concept 12

Limbs emerge from the trunk; the trunk is an interconnection, or continuum, of the limbs.

We are similarly invited to consider the relationships between the upper and lower limbs. Even though our arms and legs have evolved to manage different loads and maneuvers, it is useful to reflect on their equivalence, certainly from a postural point of view. David Keil writes about his observations of the upper and lower limbs in comparison to one another, likening the deltoids to the gluteals.[56] In a practical sense, we explore and compare the upper and lower limbs, in that they can both do some of what the other can.

Although we are moving away from parts-list thinking, it can be handy to see how some of the classically named bits of anatomy mirror one another not only bilaterally, but also as pairs of limbs. In arm balances, for instance, the arms can behave as the lower limbs and take on functionality similar to the legs in the anatomical position. When the forearms are in grounding mode, or pronation, the hands can become more like the feet. Rotational patterns of the arms in handstand echo what happens with the legs in a footstand (i.e. what we think of as ordinary standing). This approach to anatomy is rooted in the Five Filaments, the constraints-based movement rubric proposed in this book.

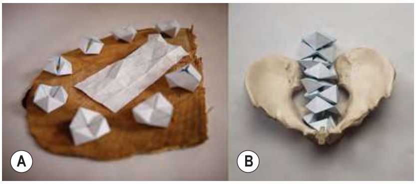


FIGURE 1.21

Constraints: 3D flexagon (you can make one yourself to get a feel for morphological constraints. (A) In the centre, the paper shows the creases that guide how the shape comes together and continues to move. (B) The particular features of the flexagon make it an interesting model for tissue. (Find another example of this topology in Chapter 3, and another relating to spirality in the Reflection and Growth chapter available online.)

Origami is an excellent example of how constraints shape movement.[57–59] You can fold and crease paper to direct its deployment into shapes. Extra creases will impose new constraints on a piece of origami, making it move differently. When I first started folding flexagons (see Fig. 1.21), I noticed that any extra creases would make the structure floppy, compromising the shape's integrity. Constraints shape a structure, and we can manage the movement of that structure to reinforce those constraints. We'll come back to variations on the flexagon throughout this book.

Foot fingers

We yogis could talk all day about the hands, feet, and their tendrils, the phalanges: fingers and toes. All five toes, or foot digits, have developed as grippers of the earth. As such, they all have a likeness in the pattern of their form and function. Fingers, on the other hand (lol), have a fully developed oppositional arrangement as hand digits. Sticking out from the five fingers is the ornery pollex (Latin for "the strong one"), referring to the thumb.

FIGURE 1.22

Foot fingers and hand toes: the autopods can get a grip on each other.

Thumb-like structures appear in a vast range of species. However, the ability to oppose the *little* fingers and thumb is unique to primates. (To consider the evolving feature of thumbs check out the *alula*, or bastard wing, of a bird in flight). In humans, the thumb can move at various angles to the other hand digits and permits the delicacy of fine motor skills of which we are capable. The thumb gives us more than a grasp on our world; it allows us a vast range of creative detail and subtlety of motion unique among organisms.

Key concept 13

Hands and feet can be platforms for standing; fingers and toes are structurally similar.

Since the toes all flex in apparent uniformity, they are classically grouped in anatomy as a set of five, with no special designation given to the great toe apart from its comparison to the thumb in the nomenclature. In the Arabic language, for example, toes don't even get a special designation, they're known only as "foot fingers." In Latin, the medical terms are *pollex pedis* (meaning "foot thumb") or *hallux*.

If we consider the hallux as the thumb of the foot (in each case the attaching muscles have been given distinctive anatomical names: "pollicis" to the pollex and "hallucis" to the hallux), we can make a useful comparison. As man evolved from quadruped, the upper limbs developed increasing dexterity as a survival adaptation. Standing on tiptoe, for example, to reach up and pick small berries (and put them quickly into the mouth) would require a specific grounding through the foot and hallux, while delicately opposing thumb and fingers to select the fruit (and an organization such as the arm and hand, to eat them). Such ideas are where the understanding arises that the upper limbs have evolved to be used differently from the gravity-bound basis of the lower limbs.

In yoga, we regularly and intuitively ground through the big toe mounds. In handstands, we learn to harness the roots of the thumb and forefinger similarly. This action works through the pre-tensioned endpoints of the limbs; predisposed to have a hollowing ability in the palmar and plantar surfaces of each. In yoga, we call this amplification ***hasta*** and ***pada bandha***. Like a sprung floor, the hollowed surfaces are pre-stiffened structures and can become springier.

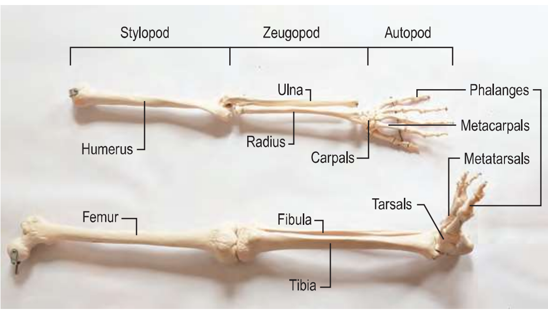


FIGURE 1.23

Stylopod, zeugopod, autopod in the upper and lower limbs.

This springy hollowing provides the body with a suitable standing apparatus by allowing that spring to extend when weight-bearing and navigating **ground reaction force** (GRF), either way up (see the **windlass mechanism** in Chapter 2). We can evoke and intensify this pre-stiffening to consciously deploy the hands into the behavior of a second set of feet, so that a handstand is functionally comparable to a footstand. In this sense, if the toes are foot fingers, then similarly, we can see the hands as the feet of the arms.

Key concept 14

Limb structures broadly reflect one another.

We explore this in yoga. However, there are biological limits that honor the innate structure of each. Interestingly, the overall pattern of one proximal bone, two distal, three then four to shape the wrist and ankle bones respectively and then the pattern of the digits in both sets of paddles are similar. Their overall structures embody different kinds of force transmission, so while it is fun to compare and explore – they have not evolved to be the same; or entirely different. We can stand on our hands, and we can improve ability in the feet and toes to advantage – however, their respective structures are naturally constrained and organized to excel at different things.

According to Jaap van der Wal, the mandible might be considered the uppermost limb, fused (only) in the human jaw structure (in all other species with a jawbone, it is formed of two bones joined via a symphysis). This is a fascinating consideration; that the feet rotate outward and cannot be joined wholly – while the mandible rotates inward and is fused. The arms then become the median limb-set, since they can be held together or held apart. They can functionally achieve some of what the other two sets of limbs are organized optimally for, but are not fully constrained to either.

Joanne Avison

FIGURE 1.24

Human fetal legs at 16 weeks. The fetus can now grab and pull the long umbilical cord. The skeleton consists mainly of flexible cartilage, the soft precursor to bone.

(Lennart Nilsson, TT/Science Photo Library)

1.7 A more useful neutral

All this talk of foot fingers can leave you feeling a bit upside down and back-to-front! To reset the view, let's stop to consider the so-called anatomical position. The AP, such as it is defined in the study of anatomy, is the place at which we have arrived for determining anatomical terms of movement and position of human parts. It makes perfect sense for bipeds planning to walk exclusively on two feet, and for patients being discussed in the third person.

Having a consistent reference position means that two practitioners, for example, can refer accurately to specific points on the body, or particular actions/ranges of motion, relative to a common denominator. This is vital for doctors looking at scans to find pathology. For yoga practitioners considering the full spectrum of movement, however, the standard anatomical position becomes less useful.

Key concept 15

For a positional basis of yoga anatomy, we often need something that is less preferential regarding which end is up.

For the living yoga practitioner, perhaps a neutral position is more usefully considered a ready stillness that allows us to formulate a language of useful landmarks. It's like having the car in gear, the clutch with bite, prepared to release the handbrake. In a state of continuous preparedness, the pre-tensioned system is spiral bound and poised to balance itself from equilibrium, independently of its position relative to the ground and gravity.

Taking the body into a handstand position is a reminder that the upper limbs can manage ground reaction force similar to the lower limbs (given appropriate circumstances). Handstand is another option for an anatomical position that illuminates positional polarity. The **vestibular** sense tells us when we're upside down,[60] and along with clear physiological cues (your face going red, for example), it is evident that the head has evolved to be on top. But hear this: the body self-organizes independent of gravity. In asana, we are playing with the **hierarchy** to find equilibrium in every position.

Biologic tissue lets living organisms, unlike skyscrapers and buses, adapt when overturned. When we consider the human body as a biped able to walk on either pair of its legs, its ultimate adaptability is easier to foster and explore. Yoga practitioners are, in particular, interested in pushing the boundaries to explore our relationship to gravity in all 360 degrees. The new paradigm offers the language we need to talk about it (head to Appendix A for more on biotensegrity).

As capacity increases, asanas can progress toward inversion. This inverse relationship continues as a defining experience, keeping the human body sprung regardless of position relative to the earth. In short, it doesn't matter which end happens to be up, on its side, front, or back. A neutral position is something of a shifting goalpost as we start seeing the body as a matrix of spirals rather than a collection of levers and pulleys in continuous compression following Newtonian laws of linear proportionality (see Table 1.2).

Table 1.2 Newtonian mechanics			
Newtonian law (approx. date)	**Subject**	**Conventional assumption**	**Comparison in anatomy**
Euler's formula (1757)	Buckling of slender columns	This law says that taller columns are weaker and less stable, so that very tall columns will bend under their own weight.	The spinal "column" should not be able to hold itself up if this formula applied.
Galileo's square-cube law (1638)	The bigger things get	This law describes proportionality in terms of surface area to volume: as the surface area of a structure squares, its volume cubes, crushing under its own weight.	Anything larger than an elephant would thus implode.
Hooke's law (1678)	as ut tensio, sic vis "as the extension, so the force"	This law talks about proportionality of how a material behaves when exposed to a force; it says that the stress-strain curve of a material is constant (linear).	Bone stiffness and brittleness is constant in animals of all sizes; why don't the long bones of humans fracture more easily than mouse bones?
Poisson's ratio (1807)	Relation to elastic moduli in isotropic solids	Describes the fundamental **elasticity** of a material. 1. A material stretched out gets thinner. 2. A squashed material bulges.	Biologic materials such as foams and crystals exhibit a negative Poisson's ratio (auxetic) making them resistant to shear and fracture.

Role Play

On the spectrum of postural yoga, what are we doing with the feet? When we aren't standing on them, we can explore, within reason, the unfolding of the feet into hand-like gestures with gradually increasing supination. It seems there is value in integrating their dexterity with foot exercises that make them more subtle and aware ears to the ground when they are in the more usual gait mode.

For me, this is about finding neutral and exploring it – rather than finding opposition. In other words: balance is the result of being ABLE to supinate and pronate; invert and evert. We explore both, but not in an attempt to make them into each other; instead, to choose balance more eloquently for them, arising between their plausible extremes. A cartwheel is fun to do, but it isn't a requisite for functional health/morphology or self-expression. Balance *is*, however.

Joanne Avison

FIGURE 1.25

(A) Anatomical position; (B) bipedal on hands; (C) supine quadruped.

(Demonstrated by Amy Hughes)

So, what is the value of making the shift into working with the body as spiral-bound? Such a system is versatile on its hands and feet. Further, we can make feet out of anything in contact with the ground: forearms, bottom, belly, crown – all take on at least a sense of the foundational foot. A neutral position is where the polar body primes itself for movement, balanced in its spirality in a state of readiness. Understanding the winding, helical nature of joint systems gives you a way to discover positional virtuosity, the beauty of neutral, and how to teach from constraints safely and intuitively no matter what style you practice.

FIGURE 1.26

The activated prone position: in Danurasana, the anterior surface effectively becomes the foot.

(Demonstrated by Fadzai Mwakutuya)

This chapter opened with an anecdote about the subtle body versus Western anatomy in the study of yoga. We asked ourselves if there could be any middle ground. Toward finding that place of integration, I dropped our pin in the embryological origins of limb rotation in human development. Considering the limbs as continuities of their original rotation in utero gives an enriched picture of the system in the long arc of its development. Keep in mind that the human organism, once emerged from its neonatal beginnings, develops in constant gravity at a relatively stable pressure. Since it does so within constraints that are continuously balancing push and pull at every scale, it makes sense that things might likely continue as they started.

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