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A SENSE OF PROPORTION

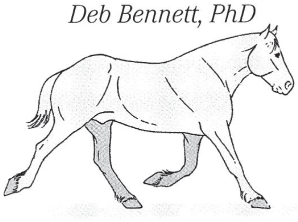
Bigger, better, faster—more! In Hollywood fantasies, that's a mantra every smart producer worships. In a competitive and sometimes cutthroat industry, the moviemaker who presents "smaller" can easily be left with a show nobody cares to see.

In recent years, a similar trend has bled over from the entertainment industry to dictate what is best for the horse owner. Large horses have dominated dressage competition since the 1970s, when Christine Stückelberger became World Champion on the huge warmblood Granat.

Gone are the days when Quarter Horses averaged less than 15 hands in height and could easily be stepped off of for roping or doctoring a calf. Letters frequently appear in my in-box from folks who are concerned that their horse isn't big enough to be a "suitable" ride—even when he's 16 hands or taller.

A horse's overall size and the stoutness of his legs govern his whole working life.

Text and Illustrations by Deb Bennett, PhD



Is bigger really better? The well-regarded all-around English horseman Henry Blake says not; in an instructive essay from the 1960s he assures us that "... the best cross-country horse I ever owned was a 13:3 hand Welsh pony that could easily clear five feet and spreads of seven feet or more." Champion show riders such as Eyjólfur Ísólfsson, who stands six feet in height, are seen on Icelandic horses that are never taller than 15 hands, and often only 13. When Ignaz Lauscha rode as Oberbereiter at the Spanish Riding School in the 1980s, not one of his horses exceeded 15 hands in height although the broad-chested Lauscha stood close to six feet tall. The winners in U.S. Cavalry trials, and similar trials in Argentina, Chile and Peru, consistently were animals less than 15 hands in height.

But in light of all the large horses now seen in so many areas of pleasure riding and showing, perhaps it is no longer enough to look in old books on stock keeping and notice that the upper limit for a riding horse's weight is listed as 1,300 pounds. Few people today understand that there's a cost for getting larger.

"Scaling" is the term used to describe the biomechanical principles that relate size and weight to the bearing strength of a horse's limbs. The scale of an animal's body determines, in large measure, how that animal is going to function. There are many things about a horse that can be modified and improved through diet, management, conditioning and training, but his overall size isn't one of them. How does this unalterable aspect of conformation impact a horse's chances for ongoing soundness and athletic performance?

WHAT HAPPENS TO **WEIGHT** AS **HEIGHT** GOES UP

Biomechanical studies often make predictions that are surprising because they're counterintuitive. When we double a horse's height, most people expect this would mean that we also double the animal's weight. However, a horse's body is not just a silhouette on two-dimensional paper. Rather, it is a three-dimensional object that has height, width and depth.

The simplest way to visualize what happens to a horse's weight as withers height increases is to consider a cube. If it measures 2 units on edge, the volume

ARND BRONKHORST; FREDERIC CHEHU/ /ARND BRONKHORST PHOTOGRAPHY

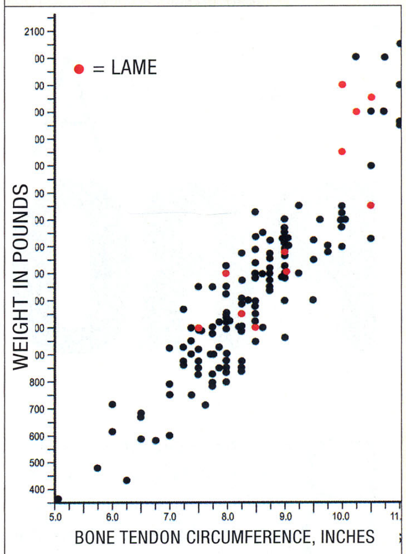
of the cube is calculated by multiplying height by width by depth, which in this case would be 2 × 2 × 2 = 8 units. The measurement of weight follows the volume. In other words, it does not matter whether the cube is made of Styrofoam, ice or lead; if you have a Styrofoam cube that measures 2 units on edge, it will weigh 8 units of Styrofoam. If you have a lead cube that measures 2 units on edge, it will weigh 8 units of lead. And likewise, if you have a flesh and blood cube that measures 2 units on edge, it will weigh 8 units of flesh and blood.

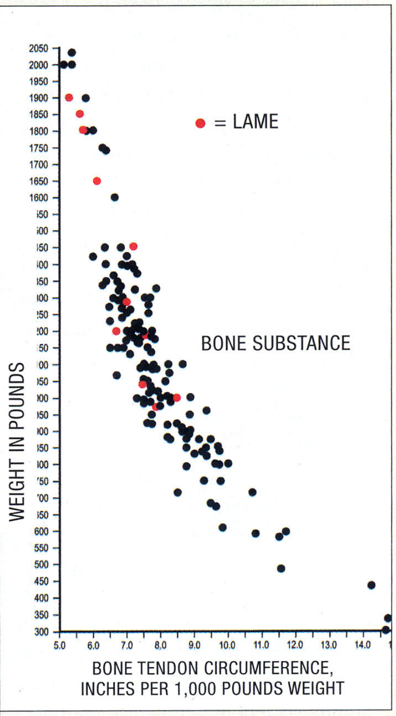
What happens if we double the height of the cube, so that it now measures 4 units high (and thus also 4 units wide and 4 units deep)? The new volume and weight will not be merely twice that of the original cube, but rather will increase by a factor of eight! This result, surprising at first glance, is the result of the new volume calculation, which says that we must now multiply 4 × 4 × 4 = 64. Originally we had a volume of 8 units; by doubling the height of the cube we get a volume of 64 units, which is eight times as great as the original volume—and hence eight times as heavy.

Whenever biomechanical calculations give us a surprising prediction like this, we should look at real horses to check whether the results are believable. According to published height-weight estimation tables, the 10-hand pony shown in the photo below weighs between 320 and 350 pounds. “Big Jim” is double his height, at 20 hands, and he weighs 2,600 to 2,800 pounds—the predicted eightfold increase.

No one is likely to try to make a horse like “Big Jim” into a performance star in dressage, jumping or reining, for the simple reason that his very size would make it impossible. However, as we drop down from horses of this magnitude into the 16- to 18-hand, 1,300- to 1,700-pound range, we find quite a number of horses today being seriously competed in riding disciplines. In last month’s installment on the riding horse physical type, I defined this as a “project.” Can the laws of physics, engineering and biomechanics help us predict whether such a project has any real hope of success?

GREAT AND SMALL: This photo of “Big Jim,” a handsome 20-hand horse exhibited throughout the United States and Europe during the 1890s, with a 10-hand Shetland stallion illustrates the huge increase in weight that must occur when we double a horse’s height.





LARGE HORSE = LARGE LIMBS AND FEET

In an online survey last year, I asked horse owners to provide basic data about their horses, including weight and anatomical measurements. Information was supplied on 160 horses, representing a wide range of breeds and cross-breeds. Comparing each horse's body weight to his bone-tendon (B-T) circumference—the distance around his leg just below his knee—the raw data fell along a relatively straight pathway that shows us what common sense would lead us to expect: Bigger horses have bigger limbs and feet.

BIGGER HORSE = LESS SUBSTANCE

When we look at B-T circumference as a percentage of body weight—a gauge of the limb's ability to support the body mass—the plot points form a curve. This tells us that limb and foot size, large though it may appear in large horses, does not keep up with increase in body mass. In other words, the bigger the horse, the less the limb substance. Survey respondents were also asked whether their horses were lame from causes known to be directly related to concussion (e.g., ringbone, sidebone, "flat soles," fractured pedal bone). Points representing those horses appear in red on both graphs—they tend to lie toward the high end of the weight range and toward lower substantialness. These data suggest that regardless of a horse's breed or weight, if his B-T circumference falls below six inches per 1,000 pounds, he has an increased chance of experiencing chronic unsoundness.

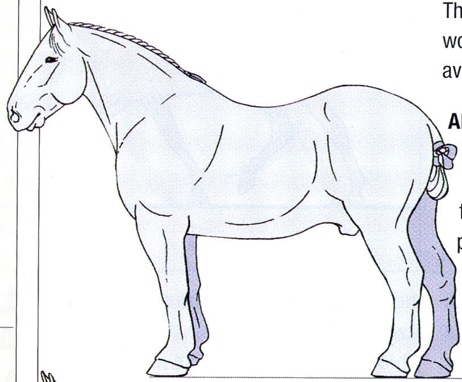
HOLDING UP THE **ROOF**, AND **MORE**

When designing a barn, a house or a skyscraper, engineers follow building codes that dictate how stout the uprights must be to bear the weight of the superstructure. In everyday terms, everyone knows that if you're putting up a pole barn, you can't support the roof with twigs. The engineering law states: The strength of a supporting member is proportional to its cross-sectional area.

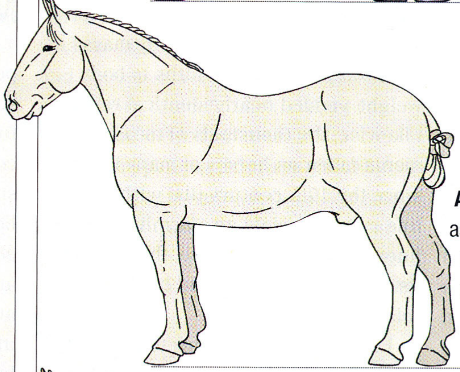
This law is used to calculate what is called "static load," the load on the uprights of a building—or on the legs of a horse when it is standing still. We are actually far more interested in what stresses the horse's limbs may be under when he moves, but in order to even

VISUALIZING **BONE SUBSTANCE**

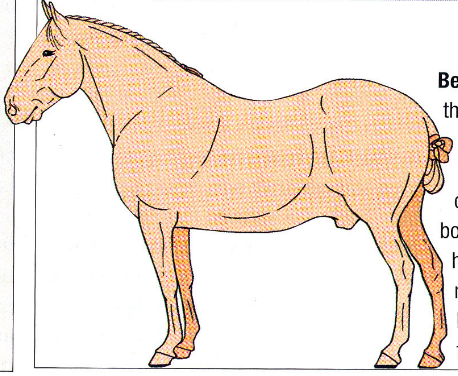
These drawings illustrate what "Big Jim" would look like if he had average, above-average or below-average bone substance.



Above average: This image shows eight inches of bone per 1,000 pounds of weight. This is the amount I recommend for riding horses, but in a horse of 2,000 pounds it would mean a B-T circumference of 16 inches. This is never going to happen and would be impractical—and probably harmful—even if a breeder could produce it.



Average: This drawing shows Big Jim as he actually was, possessing the average for horses over 1,700 pounds of six inches of bone per 1,000 pounds of weight. Big Jim's B-T circumference measured 12 inches.



Below average: This rendering shows the horse with only four inches of bone per 1,000 pounds of weight, which is 50 percent of the recommended amount of substance. A horse can have inadequate bone substance either because breeders have increased the overall size much more than the stoutness of the limbs, or because they have diminished the size of the limbs and feet.

approach that question, we must first learn a few things about static weight-bearing.

It does not matter, for purposes of support, whether we build the horse's skeleton out of Styrofoam, lead, steel or calcium apatite (the mineral substance that makes bone hard). Although these materials have vastly different strengths, the same engineering principle always holds: A thin post will always be able to bear less load than a thicker post made of the same material.

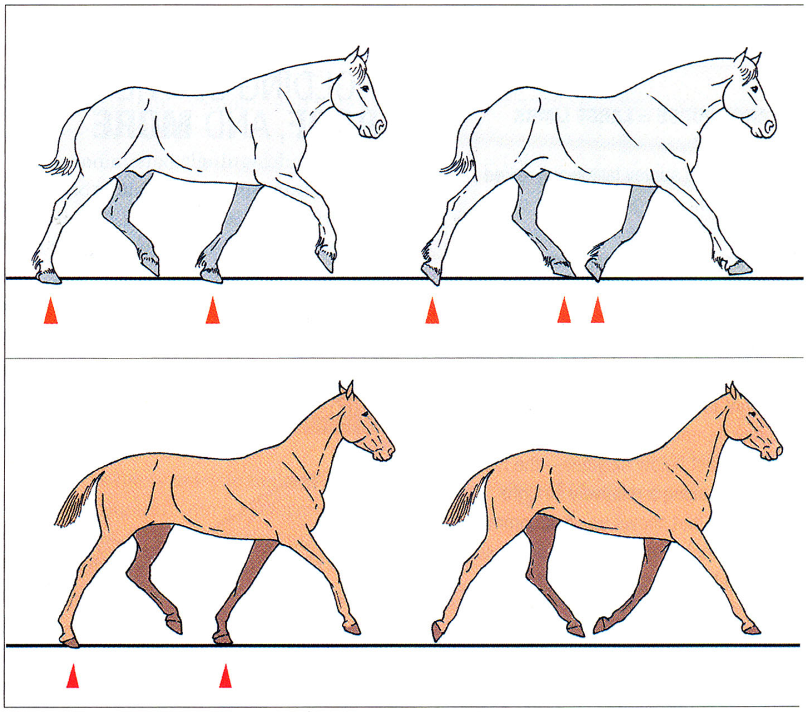
Neither does it matter what cross-sectional shape the supporting member has: It can be square, rectangular, round or shaped like an I-beam; it can be solid or hollow. As long as we continue to compare like to like, a hollow cylinder of uniformly constituted material that has the diameter of a straw will be weaker than a hollow cylinder that has the diameter of a cannon bone.

There is a practical problem in applying these principles to living horses. Although a cannon bone is a weight-bearing structural element, it is obviously not possible to directly measure its cross-sectional area in the living horse. What we can do is wrap a tape measure around the leg to obtain a circumference that includes the bone plus its surrounding tendons and other structures, the "B-T" circumference. Maximum hoof width, measured across the widest part of the hoof, is another very useful indicator of the weight-bearing capacity of a horse's limbs.

In an online survey last year, respondents reported their horses' weights and measurements; information was provided on 160 horses. When I compare B-T circumference data to body weights, the raw data fall along a relatively straight pathway that shows what common sense would lead us to expect: Bigger horses have bigger limbs and feet.

However, analysis of the same data, in which we first calculate the ratio of limb or foot size to body weight, and then compare that ratio to the overall size of the horse, yields a graph in which the plot points form a curve. This tells us that limb and foot size do not keep up with increase in body mass. Data comparing hoof widths to body weight yielded nearly identical results. Likewise, the thousands of measurements taken on horses of many breeds since the 19th century jibe with our online survey to yield an alarming bottom line: The bigger the horse, the smaller its B-T circumference and hoof width relative to its mass.

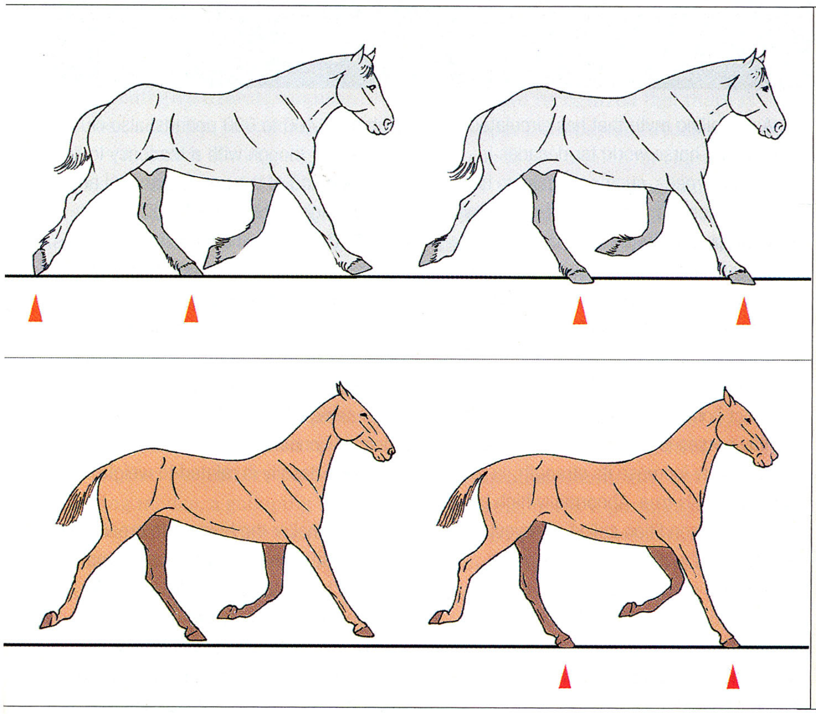
Engineering principles tell us that, as we make a building bigger and bigger, if we fail to increase the thickness of the supports as much as we increase the weight, at some point the building will collapse. That's a law of physics to which there are no exceptions. Yet even though draft horses are very big—having been bred by people to achieve height and weight far in excess of the ancestral wild horse—they still do not commonly collapse. Are there factors in living horses that allow them to push the limits of physical laws?



LIVING BONE: AMAZING COMPOSITE MATERIAL

The simple calculations we have performed so far have assumed that support materials are "uniformly constituted." But living bone is not uniformly constituted. Rather, it is organized as spongy, compact lamellar or trabecular bone—each of these types has a markedly different individual density, shape and distribution within the bone. There are two ways for a material to be nonuniform: it can contain flaws, or it can be a composite.

Flaws in bone have the same effect as flaws in nonliving support materials: They are fatal. If we look at engineers' reports as to why bridges or buildings collapse, in nearly every case the cause is related to a void or a hairline crack in some crucial support element that went undetected during structural inspections. The reason that support elements fail as a result of flaws is that cracks and voids tend to "attract" or concentrate forces. An everyday example is



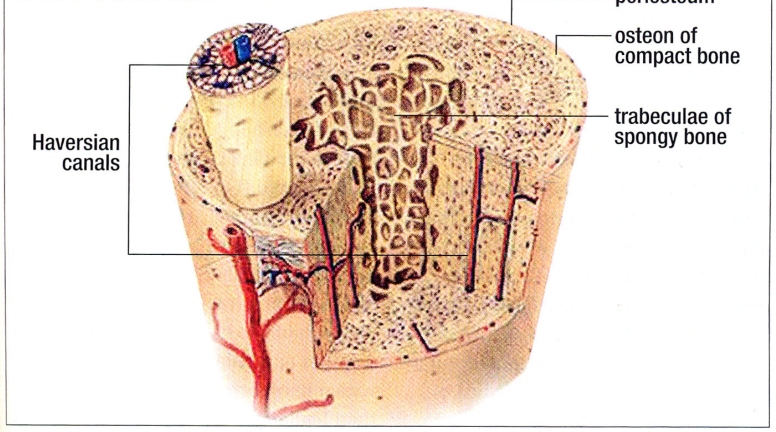
HOW **HEAVY** AND **LIGHT** HORSES TROT

NO SUSPENSION: The series at left shows the trot of a sound 1,700-pound workhorse. The red arrows mark feet that are in contact with the ground. Note that the animal has at least one foot on the ground in every frame. The "trot" is thus suspensionless, technically a form of amble. This is self-protective; as the size of an animal increases, his bones become less capable of resisting impact.

SUSPENSION: This strip shows the bouncy, suspended trot of a sound 1,000-pound riding horse. Note that he flies through the air, lightly, with no foot in contact with the ground, in two out of four frames. Horses that are lighter in weight have a much easier time thrusting themselves into the air. They are, in short, more powerful pound for pound than are heavy horses.

that little crack in your car's windshield. It may begin small, but given time, it will eventually split the whole pane. If a pebble dings your windshield, it knocks out a conical divot that, over time, forms an ever-widening concentric set of rings connected by tiny, forking cracks. Eventually the cracks will become numerous enough that a small amount of pressure is all that is required to shatter the pane. Similarly, failure is most likely to occur when flaws lurk within a bone. The most common structural flaws in the bones of performance horses are microfractures such as "shin splints" or "sore shins" and deficits or voids such as those associated with osteochondritis° dissecans (OCD) and navicular° disease.

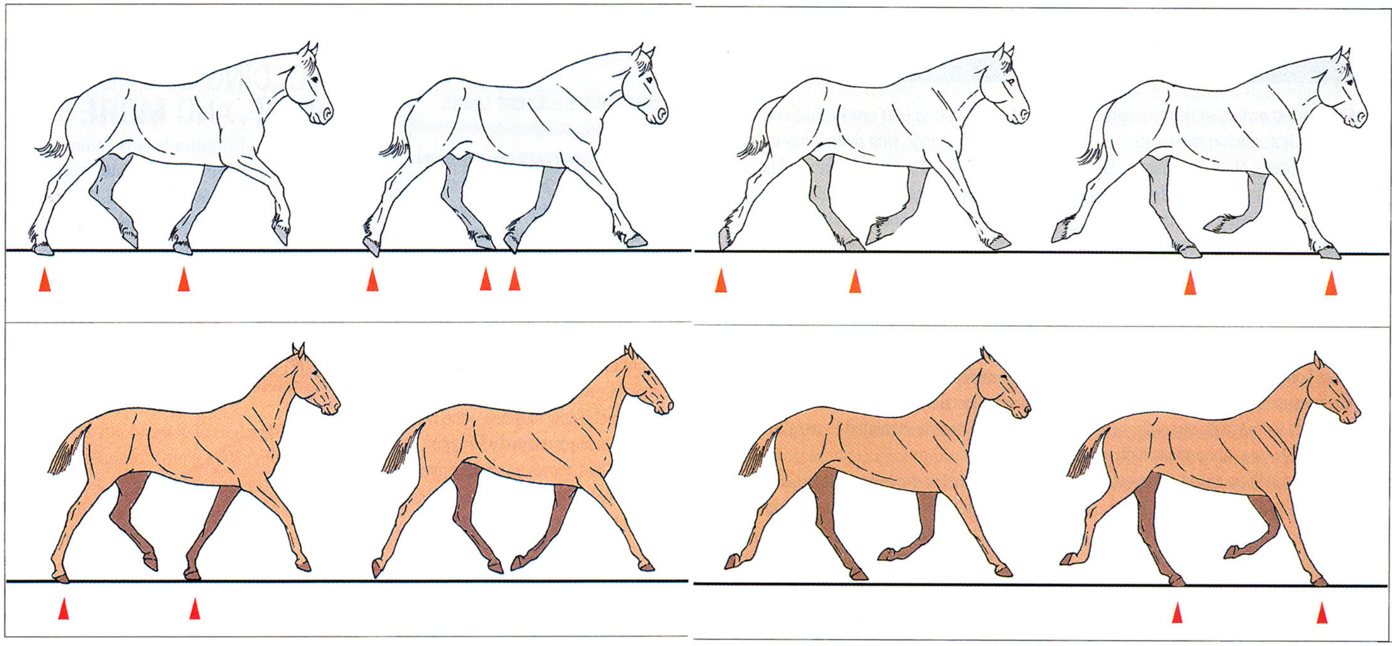
Bone is penetrated throughout by tiny, tubelike Haversian canals. It has spongy and trabecular structure near the bone ends, and compact lamellar bone coating the surface and strengthening the shafts. Although these variations make bone a nonuniform material, such irregularities are not flaws. Bone-shattering studies in the laboratory show that the internal structure of bone actually helps to disperse and diminish forces and to stop the propagation of microfractures.



bone structure

While the mineral calcium apatite is the substance that makes bone hard, every bone begins embryonic development as a mass of collagen fibers. The collagen-fiber matrix remains in every normal bone throughout its lifetime, and its form dictates where calcium apatite will be deposited. When resisting tension (pulling force) and bending forces, weight for weight collagen is stronger than steel. Yet despite its hardness, thanks to its internal collagen-fiber matrix, bone is remarkably elastic. A healthy collagen-fiber matrix is crucial to the bone's ability to resist snapping both under static loads and in movement.

Collagen strands are not permitted



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to degrade in a healthy horse's bones, for living tissue has one major advantage over steel, wood or plastic: It can heal itself. Bone is inhabited by millions of cells that repair minor damage to collagen and calcium apatite almost as soon as it occurs. Moreover, the same cells are equipped to detect the nature and direction of forces exerted upon the bone, and to respond to these stresses by either depositing or removing material. As a museum display, the bones of a horse skeleton may look fixed and unchanging—but when the animal was alive, thanks to the constant activity of bone cells, its bones were constantly changing to adapt to changing stresses. This turns out to be a very good thing indeed as soon as the horse takes even a single step.

FORCES **MULTIPLY** IN MOVEMENT

Bone is a complex, living composite material that has highly superior strength and resiliency. Fresh compact bone loaded parallel to its "grain" (the direction of most of the Haversian canals, generally the long axis in limb bones) will bear a static load of 19,000 to 30,000 pounds per square inch (1,330 to 2,100 kg/cm^2). This is roughly four times the compressive strength of concrete.

When compressive stress is applied at an angle to the long axis of the bone it is called shear stress. The resistance of compact bone to shear is also quite high, from 7,150 to 16,800 pounds per square inch (500 to 1,176 kg/cm^2), depending upon the angle at which the shear stress is applied.

These figures make it clear that the weight-bearing capability of bone is far higher than the weight of even the heaviest horse—and from this one might reason that the skeleton is so vastly over-designed that it would never break down in normal activity. Indeed, bone fractures due to compression alone are the least common class of injury.

However, in strenuous activity, other types of forces—including twisting, bending and shear—often combine with compressive stress. Through acceleration, deceleration and the concussion of impact, the pulls focused on the skeleton by tendons and ligaments may raise the total force acting upon a bone above its design limits. When this point is reached—in bone as in any other material—damage or even catastrophic failure will occur.

CONSIDERING **BONE** DENSITY

A prevailing myth that has circulated through the horse world for decades is that some breeds, such as Arabians, have denser bones than others, and I am often asked about this in my seminars.

I have two points to make. First, density means mass per unit volume. This implies nothing about the "quality" of bone, which comes from bone's internal structure—the distribution of Haversian canals, trabeculae, compact bone in the shafts—which in all healthy horses is alike. Nor does increasing bone density increase its strength; in fact, the opposite is true. Abnormally high bone density is a condition called pachyostosis; osteoporosis is its opposite. We want neither one in our horses.

Second, back in the 1980s, I was involved in a study measuring the density of equine cannon bones in the collection of the National Museum of Natural History (Smithsonian Institution). Over subsequent years, I have added still more specimens to the original data set, so that it represents domestic horses spanning a wide range of breeds—from miniature ponies to draft horses.

I found that virtually all horses in the riding weight range, from 900 to 1,300 pounds, cluster near the normal bone density, which is about 19 grams per cubic centimeter, with a range from 15 to 22. No breed in this range has significantly denser bones than any other. Riding ponies, which weigh from 400 to 900 pounds, also cluster near normal, though with a tendency to lie at the high end of the normal range. Larger horses, weighing between 1,300 pounds and 1,700 pounds, show a tendency to cluster toward the low end of the normal range. The biggest horses, weighing over 1,700 pounds, show lower frequencies of normal bone density, with many individuals falling below the normal range.

These results point toward some important conclusions:

- Bone density is related to weight, not breed.
- The smaller the horse, the greater the chance that bone density will be normal.
- The larger the horse, the lower the bone density is likely to be.

If I were raising draft horses, I would feed them digestive aids and provide them with the best quality forage, carefully balancing the mineral content. Also, consider this principle: As a horse increases in size, his body mass increases in three dimensions, but the surface of his teeth is a plane, which increases in only two dimensions. It is therefore not possible for a horse's teeth to keep up with mass increase, and the larger the horse, the greater the discrepancy will be. The only way to make up for it is either to require the animal to spend more hours per day chewing food, or to provide a very high-quality diet.

It is not easy to precisely measure the stresses acting upon bones when the living body is in movement. Bioengineers have used a number of ingenious methods, such as cutting bonelike shapes out of sheets of Plexiglas. When the models are then loaded and viewed under polarized light, colored lines appear in the plastic wherever stresses are concentrated. Other researchers have put bones into hydraulic presses and then attached strain gauges or used high-definition photography to detect deformation. Another approach is to paint the bone with a hard, brittle lacquer; when it is then loaded, micro-cracks appear in the lacquer in a pattern that indicates the array of stresses at the surface. None of these methods is entirely satisfactory, although all give useful insights.

Better, although practically more difficult, is to attach strain gauges to the limbs of living animals. By this means, maximum stresses during locomotion have been estimated for the leg bones of a wide range of wild species. Animals that have been studied differ in weight by a factor of 25,000, and range from small species such as chipmunks and ground squirrels up to the very large, such as rhinoceroses and elephants. Amazingly, in these tests all results were similar: No matter whether in a scurrying mouse, a galloping buffalo, a charging rhino or a running elephant, the maximum stress values recorded during the most vigorous forms of movement in each species turn out to be almost exactly equal to the breaking strength of bones.

Since the breaking strength of bones is far higher than the animal's weight, this constitutes clear proof that forces generated during movement are normally tens or even hundreds of times higher than they are when the animal is standing still. This jibes with the observation that horses do, in fact, sometimes break bones during athletic activity.

A SENSE OF **PROPORTION**

"Wild animals," observes biometrician Knut Schmidt-Nielsen, "are smoothly functional systems in which both structural material and chemical energy are used with economy. It is quite possible ... that a design that is optimal in one respect is not necessarily optimal in regard to another. For example, a requirement for economy of material may be in conflict with the need for structural strength. This means that different requirements must be balanced, and in order to obtain an optimized solution we would optimize not each process separately but some combination of the two that would give a unique solution."

This is exactly what knowledgeable and sensible horse breeders have tried to do over the span of many centuries. They have recognized that there is an upper limit beyond which a horse ceases to be suitable for riding. Beyond about 1,300 pounds, due to nothing more than scale, it is simply not possible to obtain the same style of ride.

With massiveness comes diminished durability—yet durability is, or should be, a prime characteristic in a horse of riding type. Massive horses are great for what they're intended for: pulling plows, sledges, carriages and wagons at a walk or nonsuspended "trot." But they are not biomechanically "optimized" for riding, nor is it possible to make them so except by reducing their overall size. Massive horses are prone to injury and chronic lameness when they are asked to do a riding horse's proper work: trotting, cantering, galloping, speed work, sharp up and down transitions, and jumping.

Hopeful monsters are rarely winners. The ordinary owner does not possess the resources of an Olympian (on-call veterinarian and chiropractor, massage therapist, professional groom) for shoring up a very large and only marginally sound horse. Neither would most people be satisfied to know that their horse's likely working lifespan is anything less than 10 to 15 years.

I advise you to select a horse for riding use that weighs less than 1,300 pounds. This conforms with scientific results and the laws of biomechanics, yet still provides a very wide range of choices. The rider who chooses a horse whose size is within the range of riding horse type reveals that he has a sense of proportion—a factor that not only underpins conformation analysis, but one which, in another sense, lies at the heart of courtesy to the animal.

For instructions on measuring your horse and other information about anatomical proportion and substance, go to

www.EquusMagazine.com