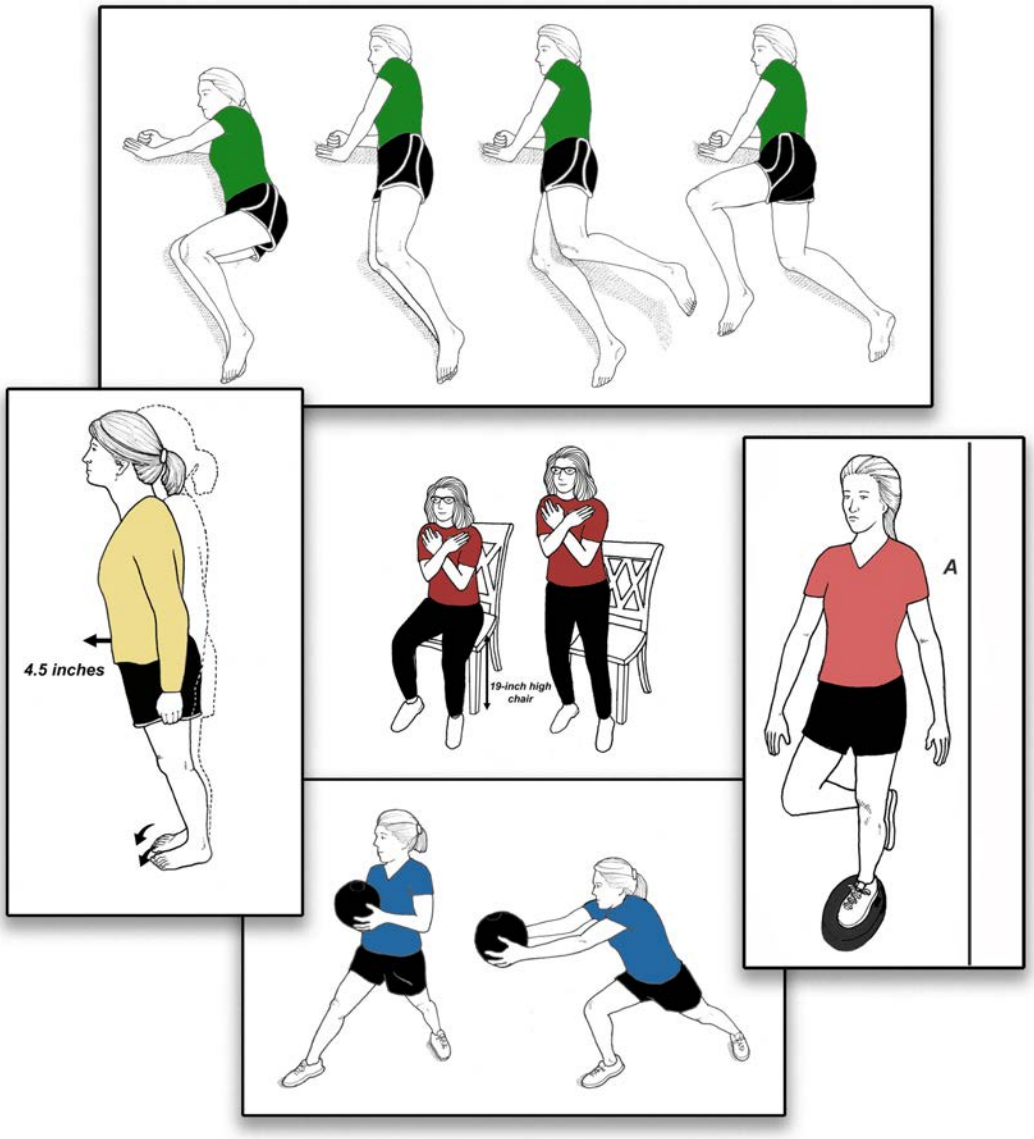
The Human Locomotion Fall Prevention Protocol:

How to Create a Customized Treatment Program to Maintain Strength and Agility as You Age



Written & Illustrated by Tom Michaud, DC

A video of this entire program is available at www.humanlocomotion.com.

Disclaimer: *Even though these exercises are safe and easy to perform, you should consult with a healthcare provider prior to initiating this program. It is especially important to consult your doctor if you have had previous falls, and/or if you have any of the risk factors listed in Table 1 of this paper. The application of information from this article is at the sole discretion of the reader.*

In his 1994 textbook, the gerontologist Bernard Isaacs states "*It takes a child one year to acquire independent movement and 10 years to acquire independent mobility. An old person can lose both in a day*" (1). The statistics on falling in the elderly are shocking. In an average year, nearly 40% of people over the age of 70 fall at least once (2), and one in 5 of these falls results in serious injury (3). In the United States, this translates into 36 million falls, 8 million injuries, 3 million visits to the emergency room, 900,000 hospitalizations, and 300,000 fractured hips (4). Nearly 25% of the people who fracture their hip will be dead in one year, and 50% of them will be unable to return to their prior level of function (4). The prevalence of fall-related injuries is just as bad in other countries. In Europe, the total number of fall-related deaths has increased steadily since 1990, and the Global Burden of Disease Study reported nearly 17 million years of life lost from falls in 2017 alone (5).

Putting aside the emotional toll of dealing with fall-related injuries, the financial costs are staggering. In 2015, the medical costs for managing falls exceeded $50 billion, and our overstressed Medicare/ Medicaid system paid for 75% of these costs (6). To make matters worse, the prevalence and costs associated with managing fall-related injuries is about to skyrocket as the percentage of our population over the age of 65 continues to increase. In 2019, one in 11 people were over the age of 65, but by 2050, one in 6 people will be over 65 (7). The number of people over 85 is increasing at an even faster rate, growing from 6.6 million in 2019 to 18 million by 2050. What I find most alarming is that fall rates continue to increase even when adjusting for age: the CDC reports a 30% increase in the rate of falls between 2009 and 2018 (4), which greatly exceeded the increase in the number of people over the age of 65 during that time period. Part of the reason for the increased frequency of falls is that we are becoming weaker and frailer. It is not uncommon for people over the age of 80 to spend more than 12 hours a day sitting. Inactivity results in muscle weakness, reduced mobility, and impaired balance, all of which greatly increase your risk of falling.

The good news is that you don't have to get weak and frail as you get old as a growing body of research is showing that fall rates can be appreciably reduced with simple exercise interventions (8,9). Although falls are often multifactorial and result from a combination of risk factors (see table 1), a large percentage of falls can be traced directly to age-related declines in strength, balance, flexibility and/or variation in foot architecture, such as the presence of flat feet, bunions, and/or hammer toes, all of which have been proven to increase your risk of falling. Fortunately, it is easy to identify the specific factors that increase your fall risk by performing a series of 14 evidence-based tests described later in this booklet. Information obtained from these tests allows you to design a customized treatment routine that incorporates any of 12 interventions that target the particular weak points identified during testing. Because the tests described in this booklet have proven reliability, they can be repeated every few months, which is a great motivator as improvements occur surprisingly fast.

While this fall prevention program is usually recommended for people over the age of seventy, I strongly recommend you start performing these stretches and exercises while you're in your fifties and sixties. As demonstrated by Faulkner et al. (10), shortly after you turn fifty, you begin to lose nearly 2% of your muscle fibers each year, and the reduction in muscle mass is associated with a 3-fold decrease in strength and power that correlates strongly with disability, falls, and reduced lifespan. The authors point out that the speed in which muscle fibers deteriorate as we age "is largely dependent on the habitual level of physical activity of the individual." In addition to improving strength, balance, and agility, a well-designed fall prevention program has the added benefit of reducing rates of depression (11).

Use of Specific Medications
Antidepressants: *Elavil, Nortriptyline, Lexapro, Zoloft, Celexa*
Pain medications: *Percodan, Percocet, Vicodin, Dilaudid, Fentanyl*
Sleep medications: *Ambien, Lunesta, Sonata*
Muscle relaxants: *Flexeril, Robaxin, Parafon Forte, Norflex*
Antianxiety medications: *Ativan, Valium, Restoril, Xanax*
Antipsychotic medications: *Haldol,Trilafon, Prolixin*
Antihistamines: *Benadryl, Dramamine*
Antiseizure medications: *Lamictal, Neurontin, Topamax, Tegretol*
Blood Pressure medications: *All BP medications increase fall risk.*
Visual Problems
Macular degeneration and/or cataracts
Loss of low contrast visual acuity
Wearing bifocals outdoors
Impaired gaze stabilization from stroke or vestibulopathy
Inner Ear Disorders
Benign paroxysmal positional vertigo (BPPV)
Presbyvestibulopathy (age-related impaired vestibular function)
Neurological and/or Cardiovascular Disorders
Multiple sclerosis, Parkinson's disease
Postural orthostatic hypotension
Peripheral neuropathy
Miscellaneous Factors
Vitamin D deficiency
Home hazards: *Uneven steps, slippery tub floors, loose throw rugs*
Poor footwear and/or foot pain
Anxiety disorders, particularly the fear of falling
Osteoarthritis of the knee and/or hip

Table 1. Risk factors for falling. Note that many of these risk factors can be favorably modified by closely monitoring medications, wearing corrective glasses, undergoing vestibular rehab when appropriate, and addressing foot problems with specific stretches, exercises, and/or orthotics. Lastly, vitamin D levels should be checked regularly, and home hazards should be identified and corrected.

Strength Tests

Toe Strength: Surprisingly, the single best predictor of a senior citizen falling is toe strength. In a prospective study of 300 older adults, Mickle et al. (12) discovered that non-falling seniors had 20% more toe strength than the seniors who fell. Interestingly, there was no difference in quadriceps or ankle strength between the fallers and the non-fallers, confirming that toe weakness, not generalized weakness, is responsible for the falls. Unfortunately, toe weakness is extremely common in seniors: compared to their younger peers, older adults have toe strength declines of more than 35%, which greatly increases the risk of falling (13). Strength in the big toe is especially important as it is one of the best predictors of impaired balance in the elderly (14).

To understand the connection between toe strength and falling, stand with your arms at your side while keeping your hips and shoulders in a straight line. Now, maintain this straight alignment while you lean forward: notice how your toes, especially your big toes, immediately push down into the floor to protect against a forward fall (Fig. 1). The distance you can lean forward while keeping your balance is called the anterior fall envelope, and the seniors at greatest risk of falling can only lean forward a few inches before losing balance. Strengthening the toes increases the length of the anterior fall envelope and can reduce the risk of falling by allowing you to control the subtle forward lean that begins while reaching forward to grasp an object, and/or while leaning forward to initiate your first step while walking (the two most common times for a fall to occur).

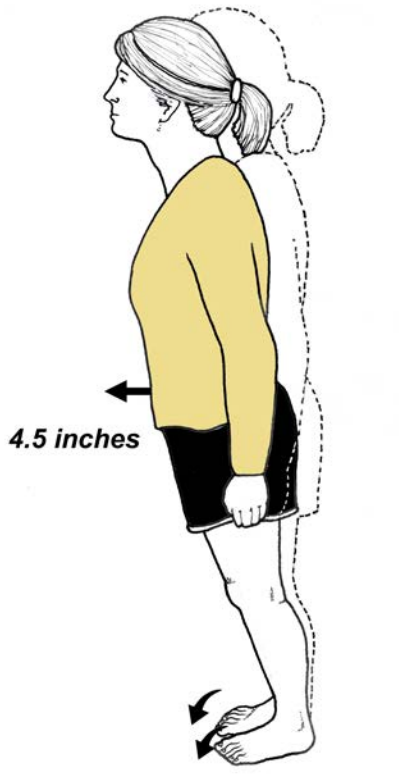


Fig. 1. The Anterior Fall Envelope.
While standing upright with your arms at your sides, gradually lean forward as far as you can while keeping your hips and spine in a straight line. Notice how the final degree of forward lean is controlled by the amount of pressure you generate beneath your toes. Ideally, you will be able to lean forward at least 4.5 inches and the online video shows how to measure this distance with an inexpensive laser scanning device.

It is easy to measure toe strength using the toe strength dynamometer (Fig. 2). This inexpensive device allows you to precisely quantify toe strength before and after exercise intervention. A recent study from the University of Virginia showed that this test is highly reliable, and strength measurements taken on different days by different examiners are consistently reproducible (15). The initial strength scores provide the doctor and the patient clear proof of the need to perform toe exercises. The post-exercise scores also provide measurable guidelines for evaluating the efficacy of the exercise protocol. What I like about this test is that it gives an exact number that allows you to not just monitor progress, but also to evaluate the reduced risk of falling: Mickle et al. (16) show that for every 1% increase of body weight generated beneath the big toe, the risk of falling decreases by 7%. Note that the big toe alone can exert a downward force equaling 52% of body weight (17) and increasing force output by 1% is easy to achieve.

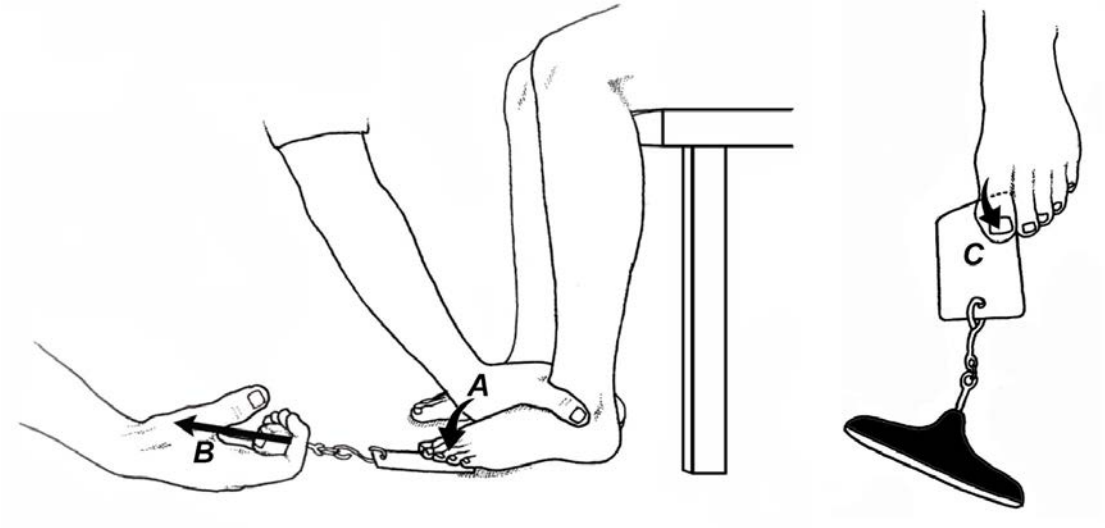


Fig. 2. Toe strength dynamometer allows you to easily measure and record toe strength. With the device placed beneath the second through fifth toes, you push down (**A**) as the examiner tries to pull the card out from beneath your toes (**B**). A digital score is recorded, and the test is repeated beneath the big toe (**C**). Ideally, you will generate 10% of your body weight beneath your big toe and 7% of your body weight beneath your little toes.

My favorite way to strengthen the toes is with the ToePro exercise platform (Fig. 3). This product was designed after research by Goldman et al. (18) showed that strengthening toe muscles in their lengthened positions produced 4 times the strength gains of conventional exercises. Unfortunately, the most popular toe exercises, including the short foot exercises, elastic bands, and marble pickups, all exercise the toe muscles in their shortened positions (Fig. 4).

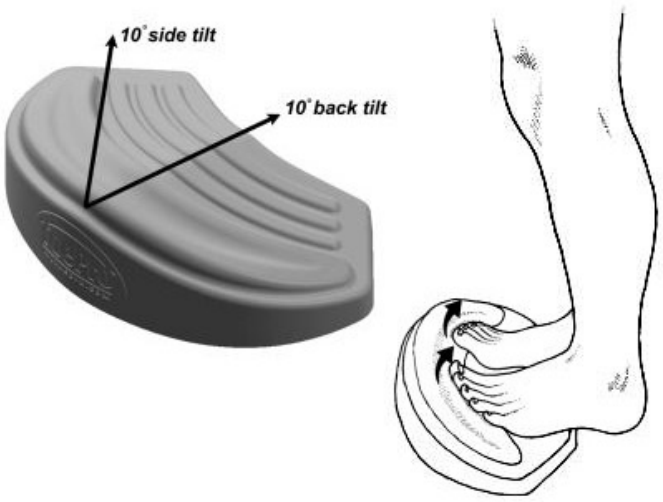


Fig. 3. The ToePro Exercise Platform. The platform is angled 10° to the side and back to stretch the calf and outer leg muscles and the crescent-shaped elevation allows you to exercise your toe muscles while they are in their lengthened positions (**arrows**).

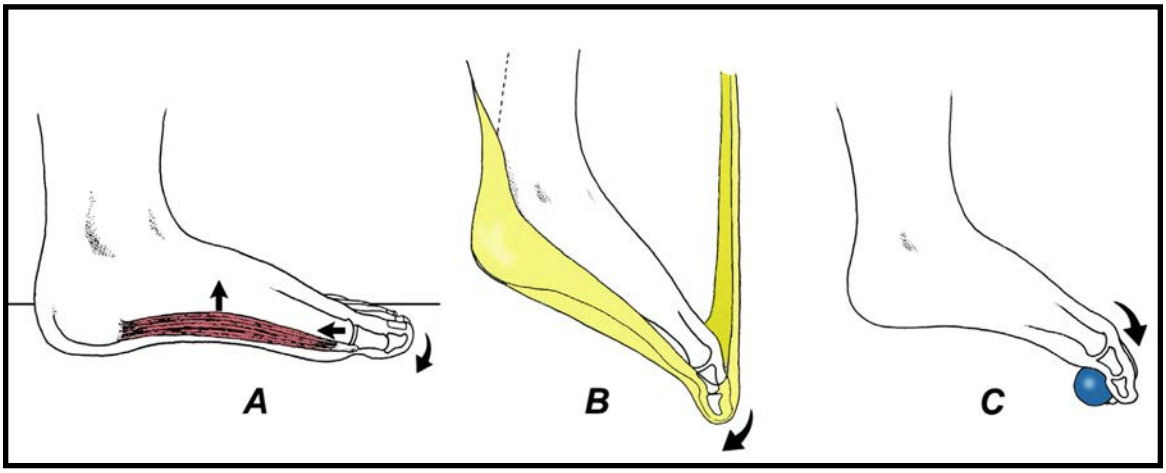


Fig. 4. Frequently prescribed foot exercises: The short foot exercise (**A**) is performed by raising your arch while simultaneously pulling the big toe towards the heel (**arrows**). Elastic band exercises (**B**) are performed by forcing the toes down against resistance from an elastic band while marble pick-ups (**C**) require you curl your toes downward to grasp marbles or stones. Notice how the toes are moving from a midline to a downward position throughout all of these exercises, which is the opposite of how these muscles function while we walk and run.

Because strength gains while exercising are angle specific (19) (i.e., strength gains are greatest when muscles are exercised in the joint angles used while exercising), to be effective, toe exercises should be performed when the toes are in their lengthened positions, which is the position they are in when exercising on the ToePro. In a 2019 pilot study, researchers from Temple University had 22 subjects perform ToePro exercises for six weeks (20). At the end of the study, subjects who were compliant with the exercise program had 35% increases in toe strength, clinically significant improvements in single-leg balance and importantly, they were able to generate more pressure beneath their inner forefoot while walking. All of these factors can significantly reduce your risk of falling.

The ToePro exercise routine is divided into 2 parts: a warm up that allows you to practice improving your anterior fall envelope, and conventional exercises that more aggressively strengthen the toe muscles. To perform the warm-up exercise, place the ToePro near a wall and stand so your forefoot is on the ground and your toes are angled up so they are supported by the base of the platform. While ToePro exercises are typically performed barefoot, they can also be done while wearing thin soled sneakers. Also, if you have bunions, you should consider wearing a toe separator while performing these exercises.

To start the warm-up exercise, keep your hips and torso aligned and slowly lean forward (Fig. 5). You'll immediately notice that your toes begin pushing down vigorously into the foam in an attempt to stop you from falling forward (which is why the wall is in front of you). Your fingertips should be close to but not touching the wall. Lean as far forward as you comfortably can and hold this position for 3 seconds while trying to stay as close to the limit of your anterior fall envelope as possible. If your toes are weak, you will have to push off the wall occasionally in order to regain balance, but as you get stronger, you can do the warm-up routine with your arms at your side. You repeat this movement 20 times and hold the final repetition for a full 30 seconds while you balance at the limit of your fall envelope.

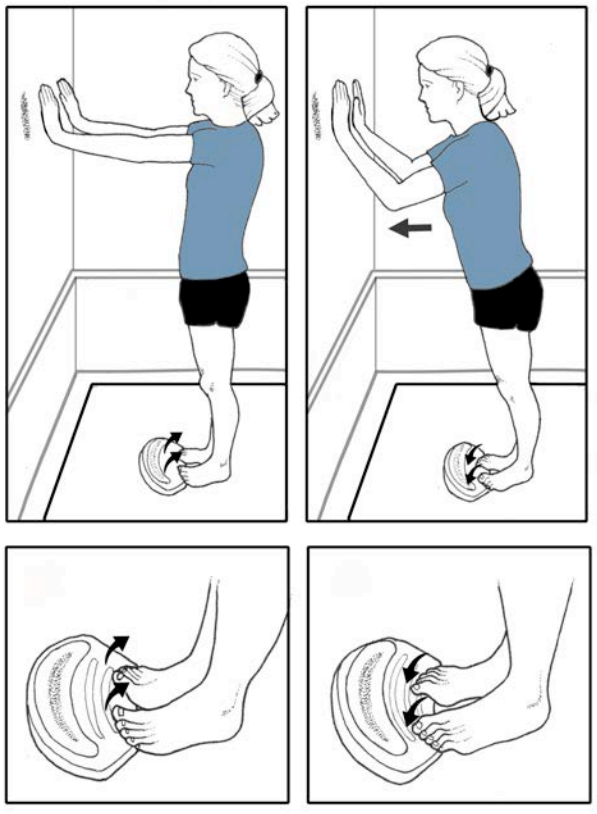


Fig. 5. Initial ToePro exercise. See text for explanation.

After completing the warm up, move your feet forward on the ToePro so the tips of your toes rest in the center of the crest while placing your hands against the wall for balance (Fig. 6). You begin this exercise with your arches elevated (Fig. 6, C). As you raise your heels, you drive your toes down into the foam while simultaneously rolling your heels inwardly (Fig. 6, D). Try doing 4 sets of 15 repetitions, with 2 of the sets performed while your knees are straight (Fig. 6, E), and the other 2 sets performed with your knees bent (Fig. 6, F).

After your final repetition, maintain an isometric contraction by trying to balance for 60 seconds with your heel 1 inch off the floor (Fig. 6, G). The addition of the isometric contraction is extremely helpful for improving your anterior fall envelope, as the soft foam beneath the toes forces your toe muscles to fire vigorously to maintain balance. If for any reason you are unable to perform 15 repetitions and/or maintain the isometric contraction, try doing the exercise next to a table and offload some of your body weight by pushing down with your hands onto the tabletop. As you get stronger, you can build to 4 sets of 25 repetitions. If you are not fatigued after your final repetition, you should do the exercises while holding onto a weight.

Besides reducing your fall risk, strengthening your toes has other benefits. Several studies have shown that toe strengthening exercises increase step length while walking (18), improve sprint and single-leg long jump performance (21), and significantly increase horizontal jump distance (18), which explains why the ToePro exercise platform is so popular in the NBA.

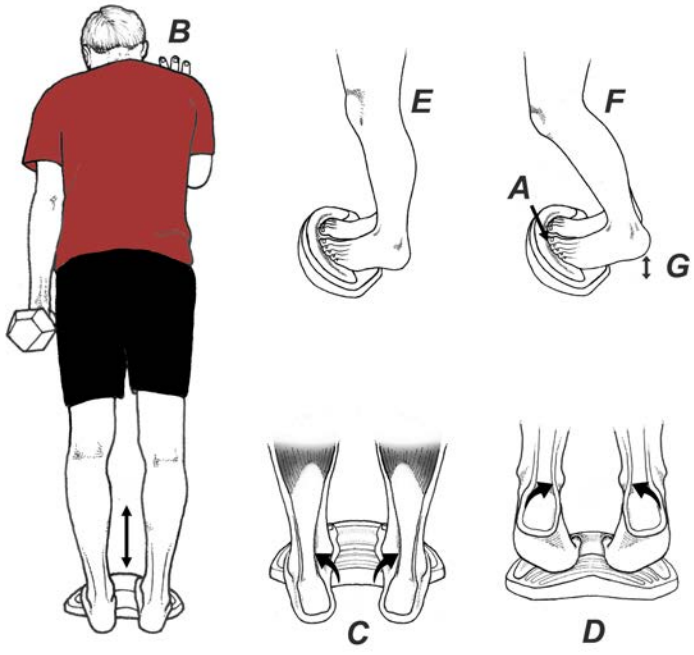


Fig. 6. Conventional ToePro exercise. Position the ToePro near a wall and place your toes in the center crest (**A**) while contacting the wall for support (**B**). Start the exercise with your heels on the ground and your weight shifted to the sides of your feet (**C**). Next, raise your heels off the ground and slowly roll inward (**D**) simultaneously pushing your toes down in the foam (**A**). Start by performing 2 sets of 15 repetitions with your knees straight (**E**) and 2 sets of 15 repetitions with your knees bent (**F**). This routine is completed by holding a 60 second isometric contraction after your final repetition, with your heel 1 inch off the floor (**G**). This exercise routine is usually performed 4 times per week.

Calf Strength: In addition to measuring toe strength, it is also important to measure strength and endurance in the lower leg muscles as weakness of these muscles has also been correlated with falls (22). My favorite way to measure strength is with the single-leg heel-raise test (23). To perform this test, place your forefoot on a ToePro or a 10-degree foam wedge that is positioned near a wall. Next, set a metronome at 60 beats per minute and begin doing single-leg heel raises keeping time with the metronome (Fig. 7). When doing the heel raises, make sure you lift your heels as high as possible for each heel raise until no further repetitions are possible. It is important to keep your knee and trunk straight during testing and only rely on mild fingertip support for balance. If you fall below the reference ranges listed for your age, you should start strengthening your calves using the ToePro exercise platform and repeat the single-leg heel-raise test in 4 to 6 weeks. When you follow the 4 sets of 25 protocol typically recommended for the ToePro, most people get to their target reference ranges for calf endurance within 2 months.

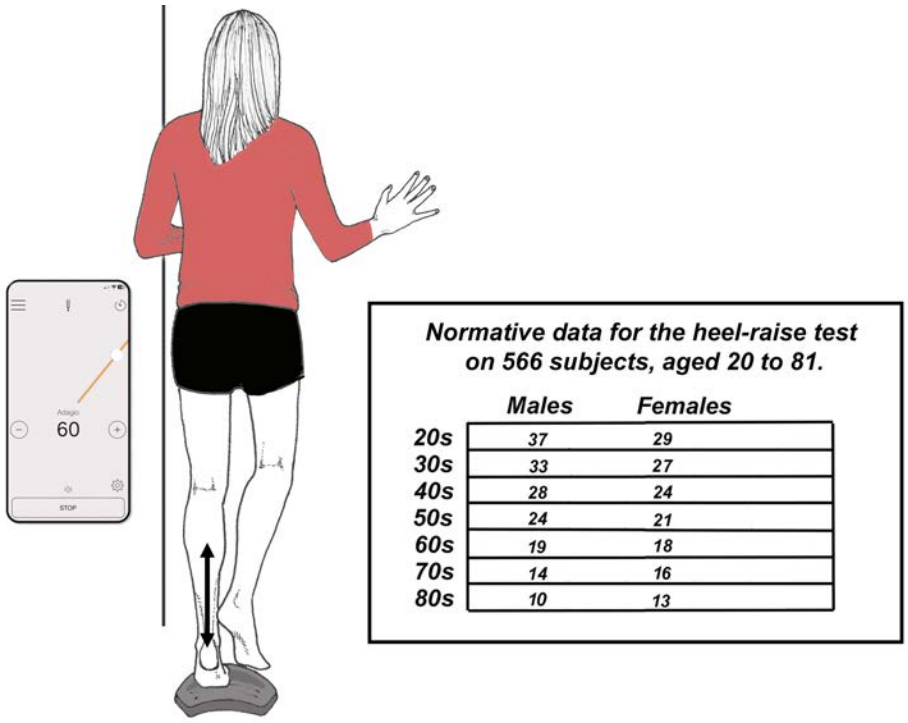


Fig. 7. The single-leg heel-raise metronome test. Place a ToePro or any elevated foam wedge near a wall and place your forefoot on the edge of the device. Next, set a metronome so that it beats at 60 beats per minute and begin doing single-leg heel raises so that your heel is at its highest point each time you hear a beat from the metronome. Do this until you are unable to repeat a complete heel-raise cycle in time with the metronome. Typical scores based on your age are listed on the right.

Quad Strength: While quad strength is not as important as toe and calf strength for preventing falls, it's important to assess as quad weakness can result in falls while going either up or down stairs (which can be disastrous). To assess strength, perform the sit-to-stand test by sitting in a standard height chair with your arms folded in front of you and time how long it takes you to do 5 sit-to-stand transitions (Fig. 8).

Failure to perform this test in less than 12 seconds is a significant predictor of falls in older adults (24), but as illustrated, the time needed to perform this test should be adjusted based on age. While poor performance with the sit-to-stand test is usually easy to fix by performing forward lunges, the safest way to strengthen these muscles is by doing the lateral step ups illustrated in figure 9. Unlike full squats and chair raise exercises, which are notorious for aggravating knee problems (25), lateral step ups effectively strengthen the quad and hip muscles while putting hardly any pressure on the kneecap (26).

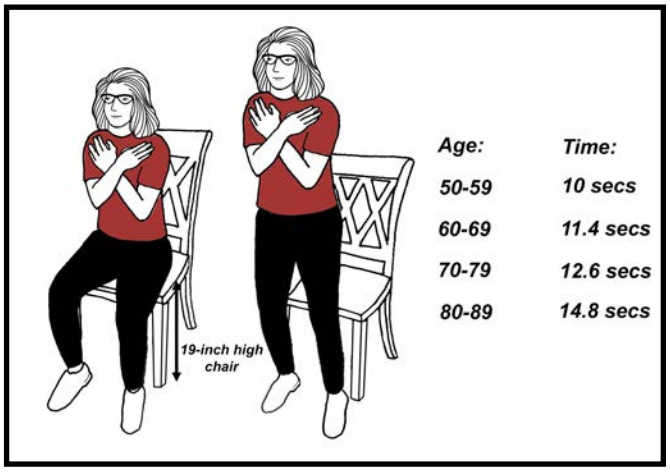


Fig. 8. The sit-to-stand test. This highly reliable test is performed by seeing how long it takes you to stand from a seated position 5 times. The time it takes to do this test varies with age. The minimum acceptable times listed on the right are taken from Wallman et al. (27).

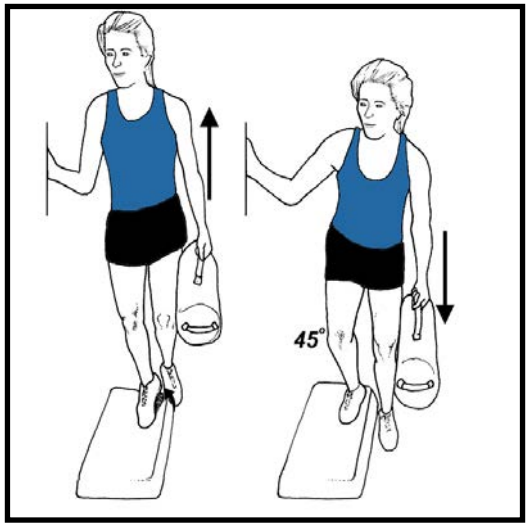


Fig. 9. Lateral step ups with weighted bag. While holding a weight in one hand, place one foot on a 4- to 6-inch platform and do 2 sets of 15 repetitions stepping up onto the platform while holding onto a wall or stable surface. The stepping knee should not twist in, and it should bend only a small amount. Bending the knee more than 45 degrees (as with squats) produces dangerous amounts of pressure on the back of the kneecap (25), which explains why people in fall prevention programs are often unable to do full squats (28). Lateral step ups have been shown to effectively target the inner quad and hip musculature, while placing very little strain on the knee itself (26). Performing a slight hip hinge while raising and lowering the weight allows you to isolate the hip rotators and abductors.

Another interesting test of quad strength that also measures speed and agility is the alternate step test (29) (Fig. 10). As the name implies, this test is performed by alternating stepping up and down with your right and left foot (shoes off) on a 7- to 8-inch step. Ideally, you will be able to complete 8 steps in less than 10 seconds (29). If you are unable to perform this test in the allotted time, you should do forward step-ups on a slightly lower platform and time the speed of your steps with a metronome set at 135 beats per minute. Do this for 30 seconds and repeat this routine 3 times, gradually increasing cadence of the metronome's beat frequency as you improve. Ideally, you will eventually be able to do this exercise with the metronome set at 192 bpm. Recent research shows that performing exercises at a rapid pace improves the speed in which muscles fire (30), which is important for fall prevention as faster muscles are able to respond more rapidly to an unanticipated loss of balance.

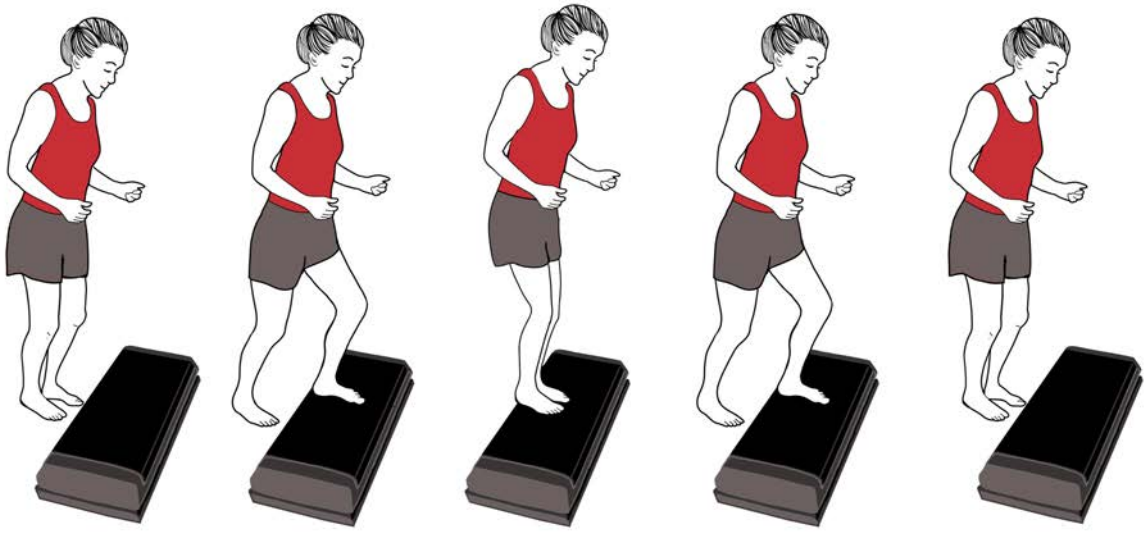


Fig. 10. The Alternate Step Test. This test is performed by alternately stepping up then down on a 7.5-inch step. For safety, the step should be positioned in front of a wall, and you should keep your arms out at all times for balance. The goal is to do a do 8 steps in less than 10 seconds.

Hip Strength: Although there's no research specifically connecting hip weakness to falls, I've included this section because strong hips, especially the hip rotators and abductors, can protect against femoral neck stress fractures should you have the misfortune of falling (31). Strong hips may also decrease the likelihood of getting a spontaneous hip fracture, in which the hip breaks while you are standing upright, and you fall as a result of the fracture.

Although not common, spontaneous hip fractures represent approximately 5% of all age-related hip fractures (32). A team of biomedical engineers from the United Kingdom created a two-dimensional mathematical model and proved the hip rotators and extensors, which are among the most powerful muscles in the body, create compressive forces that protect and stabilize the femoral head while we are standing, walking, and running (33) (Fig. 11). Keeping your hips strong is extremely important, not just for hip health, but also to protect your knees and ankles from injury (34,35).

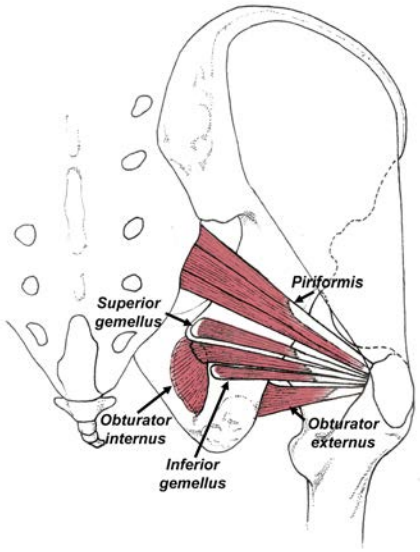


Fig. 11. The deep hip external rotator muscles. Note the gluteus maximus sits on top of these muscles and is not illustrated.

It's easy to test the strength in these muscles with the seated hip rotator test (Fig. 12). To do this test, you can use the same dynamometer used to measure toe strength, you just replace the plastic card with an ankle cuff. While seated, you should be able to generate 20% of your body weight while performing this test. One study found that college athletes who were unable to reach the target goal of 20% body weight were 7 times more likely to tear their anterior cruciate ligament (34). Prior research showed that failure to generate 20% of your body weight correlated with knee injuries in runners and ankle injuries in basketball players (35).

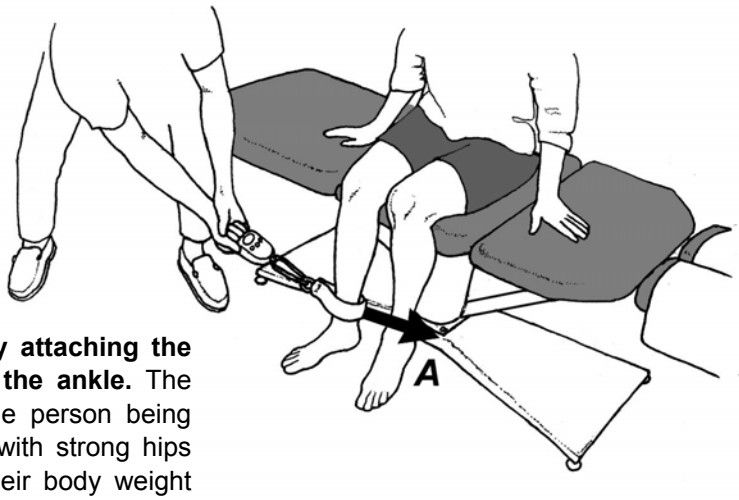


Fig. 12. Hip rotator strength is measured by attaching the strap from the dynamometer to just above the ankle. The examiner holds the dynamometer still while the person being tested pulls inwardly at the ankle (**A**). People with strong hips should be able to generate at least 20% of their body weight while doing this test.

I've noticed that older people who are unable to generate 20% body weight with this test are more likely to fall when changing directions while walking, and are more susceptible to hip fractures in general, particularly spontaneous hip fractures. I've given a wide range of exercises over the years to correct hip weakness and the exercises listed in figure 13 usually increase hip strength to above the 20% body weight mark within 6 to 8 weeks.

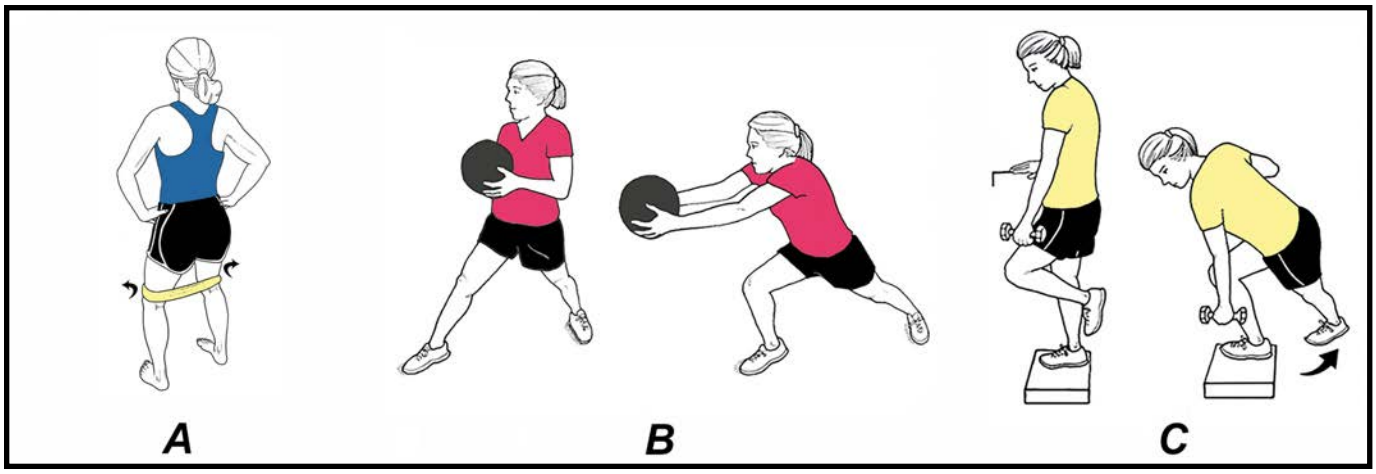


Fig. 13. The best hip and knee strengthening exercises. A) Standing clamshell exercises. While standing with your hips and knees slightly bent, push your knees out against resistance provided by an elastic band. This is a nice warm up exercise and you can start by doing 30 repetitions. **B) Fencer's lunge with rubber medicine ball:** To do this exercise, stand in a forward lunge position while holding a rubber medicine ball. Next, pivot forward at the hips while maintaining a straight spine and move the ball forward as far as possible. You should not move so far forward that you lose balance and hold this position for three seconds before returning to the start position. **C) Curtsy step up:** While standing on one leg on a 6-inch step, move the opposite leg down and back (**arrow**) as you lean forward. At first you will need to stabilize yourself with one hand while the opposite hand holds a weight. You typically perform 2 sets of 15 repetitions of each of these exercises 4 times per week.

It's important to note that even with strong hips, it is difficult to prevent hip fractures associated with lateral falls in older adults. It's a scary fact but the rate of hip fractures increases 100-fold when you turn 60, and 1000-fold after you turn 80 (36). The reason for this was unclear until recently. In an interesting paper evaluating evolutionary changes in our hips over the last 4 million years, Avni et al. (37) demonstrate that our gradual transition to bipedal locomotion produced significant changes in the shape of our hips: the femoral heads became larger, the femoral necks became more vertical, and there was an increase in the sidewards projection of the greater trochanter (Fig. 14).

Although these changes made us more efficient bipeds, they resulted in significantly more force being channeled through the lower femoral neck with less force being channeled through the upper outer femoral neck. Over time, the femoral neck remodels in response to the applied forces with the upper femoral neck becoming thinner and thinner and the lower femoral neck becoming thicker and stronger (arrows in top right of figure 14).

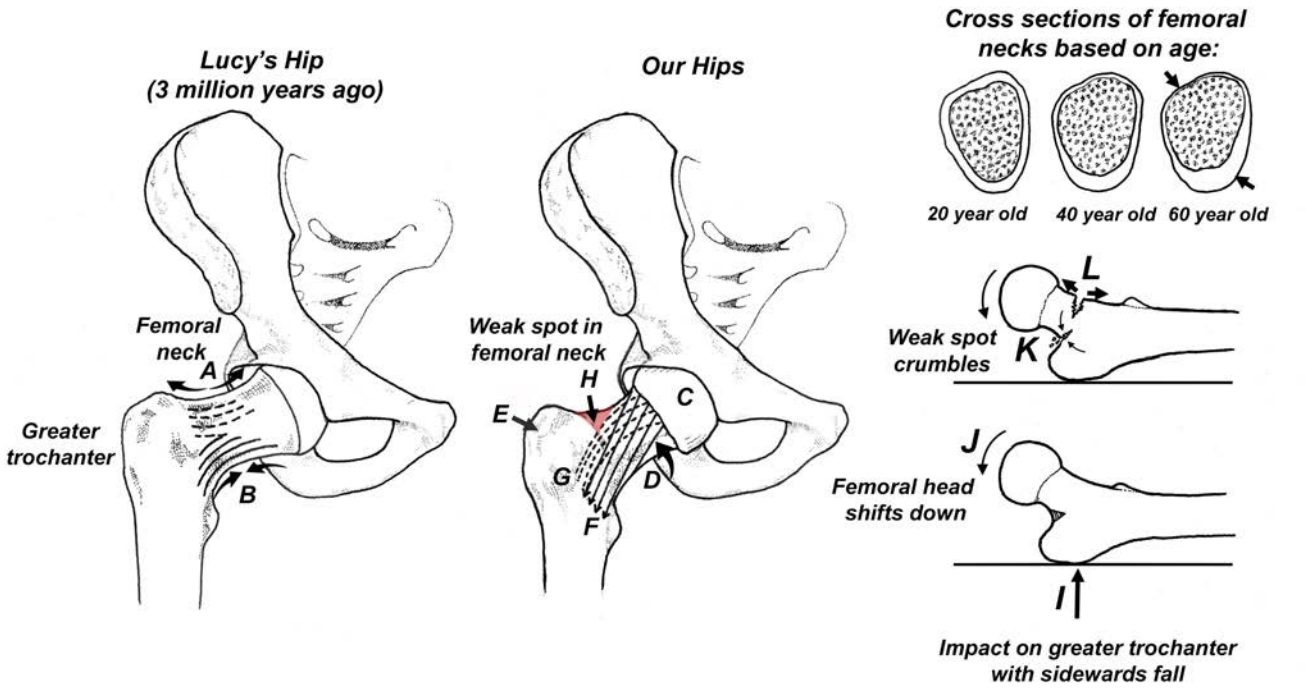


Fig. 14. Evolutionary adaptations to bipedality. When our ancestors first started walking around on 2 legs, the weight of the upper body produced significant tensile strain on the upper femoral neck (**A**), which was matched by an equal compressive strain on the lower femoral neck (**B**). Due to the magnitude of these bending forces, the femoral neck would fracture pretty quickly if our ancestors attempted to walk long distances on a regular basis. Fortunately, over the last 4 million years, our hips have adapted to the stresses associated with bipedality as our femoral heads became gradually larger (**C**), our femoral necks angled more upwardly (**D**) and our greater trochanters moved outwardly (**E**). While all of these changes made us more efficient bipeds, they changed the pathways of the tensile and compressive forces affecting the femoral neck: the compressive forces now angled downwardly from the top of the femoral head (**F**) while tensile forces were angled downward to match the femoral neck angle (**G**). The shift in the location of tensile and compressive forces resulted in the formation of a small region in the upper outer portion of the femoral neck (red area in **H**) that is shielded from force while we walk and run. Without exposure to force, this area gradually weakens over time, increasing the likelihood of a fracture. Notice how the upper femoral neck thins out between the ages of 20 and 60, while the lower femoral neck gets thicker (**arrows**). The weak spot in the upper outer portion of the femoral neck creates a dangerous situation in which a lateral fall onto the side of our hip (**I**), causes the femoral head to shift downward (**J**), which in turn causes the weak spot to buckle under the resultant compressive load (**K**). Once this area buckles, the tensile load in the lower femoral neck is drastically increased, causing another fracture (**L**). If the weak spot were not present, the resultant fractures would not occur, explaining why humans are the only mammals to fracture their hips when falling, and why 20 year olds do not fracture their hips when they fall laterally. Thin older people are especially prone to hip fractures with sidewards falls, as they have less body fat to protect the greater trochanter.

Thinning of the upper femoral neck greatly increases the likelihood that we will fracture our femoral neck if we fall on our side, as the weak point in the top of the femoral neck buckles due to the higher position of the femoral head relative to the greater trochanter. Note that this weak spot in the femoral neck is present even in people with good bone density (37).

The good news is that it may be possible to prevent age-related reductions in the strength of the upper femoral neck by performing specific exercises. In an interesting paper published in *The Lancet*, Mayhew

et al. (36) claim that it might be possible to improve bone density in the upper femoral neck by performing strengthening exercises while the hips are fully flexed, as unlike walking and running, exercising while your hips are flexed channels forces through the weak spot in our femoral necks. The authors support their statement by noting that in cultures where people squat for long periods of time with their hips flexed, like rural China (38) and Gambia (39), there is a very low incidence of hip fractures, even with lateral falls, despite a significantly higher prevalence of osteoporosis in these societies. One possible mechanism is that squatting activates the deep hip external rotators, which attach around the weak spot in the femoral neck (refer back to figure 11). It's been known for decades that when muscles contract, they pull on their bony attachment points with a significant amount of force, which in turn can strengthen that specific spot. It is also possible that these exercises produce a torque on the femoral neck itself, which accelerates bone remodeling. Either way, strengthening exercises performed against resistance can significantly reduce the rate in which our bone density decreases over time (40), and can even prevent sidewards falls as hip strengthening exercises have been proven to enhance lateral stability (41).

My favorite hip exercises are listed in figure 13, and it is also possible to strengthen your hips with stationary bike riding, rowing, jumping and/or stair climbing (36). Because peak bone density occurs while you're in your early twenties, you should begin these exercises early in life, as even though it is possible to prevent additional bone loss if you start exercising when you're older, it is difficult to reverse osteoporosis with exercises alone, as it can take decades to appreciably increase bone density in the femoral neck with exercise interventions (40).

Core Strength: Core strength is similar to hip strength in that even though there is no specific research relating it to an increased fall risk, a strong core is incredibly important as it helps you get up from the ground should you have the misfortune of falling. It's terrible to think about but nearly 50% of people over the age of 70 who fall are unable to get up on their own (41). For people who live alone, this can have disastrous consequences (42). One study of 125 people over the age of 65 who fell in their own homes found that half of the people who were unable to get up for more than an hour (referred to as long lies) were dead within 6 months (43). This does not have to be the case. According to the *World Guidelines for Fall Prevention* published in 2022 (44), there is strong evidence that balance and functional exercise programs can not only reduce the risk of falling, but they also can teach people to get up once they have fallen. Like most things in life, the ability to get off the floor is a learned skill, and this skill can be regained with practice (45). While everyone has their own preferred way of moving during floor-to-stand transitions, such as rolling over onto all fours and pushing up or performing a partial sit-up and then rolling over onto your hands and knees, the most common movement strategy requires a strong core as it involves asymmetrical side-sitting to a partial kneeling pivot off your down arm (46). Performing this movement is relatively easy but it requires a certain amount of core strength.

As demonstrated by Stuart McGill (47), the least stressful way to test your core strength is with the beginner's side bridge illustrated in figure 15. Because this exercise is done with body weight distributed

equally between both hands and your knees are being used as a pivot point, it activates all of your important core muscles while placing relatively little stress on your spine. Distributing pressure between your hands is important as it places less stress on the down arm than conventional core exercises. To test your core strength, lie on your side with your hip and knees flexed with the weight of your upper body equally supported by both arms. Next, while maintaining ground contact with the legs and the down knee, lift your pelvis up and forward, as if rising from a chair (arrow). Once you're up, you can test your core strength by seeing if you are able to hold this position for a full 45 seconds. You should repeat this test on each side.

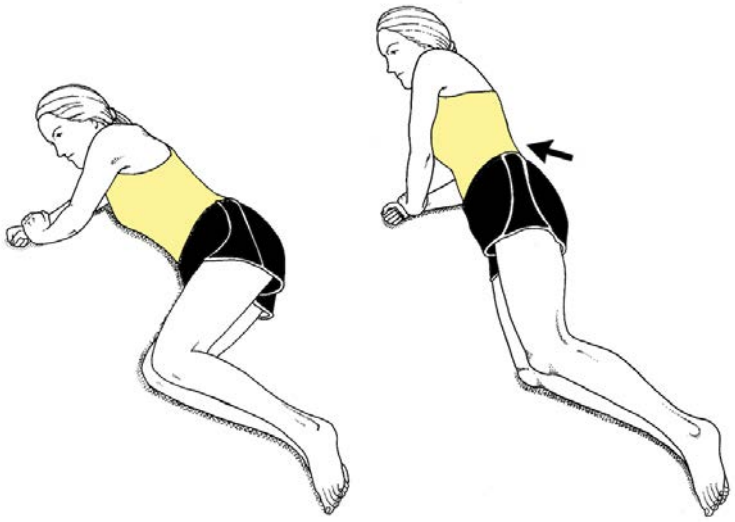


Fig. 15. Beginner's side bridge. Rest on your side with your hip and knees flexed with the weight of your upper body equally supported by both arms. Next, while maintaining ground contact with the legs and the down knee, lift your pelvis up and forward, as if rising from a chair (**arrow**). You should be able to hold this position for 45 seconds.

If your core is even slightly weak, my favorite way to restore core strength is with a modified DNS core exercise that is a part of a program called the Dynamic Neuromuscular Stabilization Approach. This approach was created by the Czech researcher Pavel Kolar, who spent his life studying movement patterns created in the central nervous system as infants progress from crawling to achieving an upright posture. Although most frequently used with high-level athletes (48), I have found this exercise is invaluable when it comes to teaching people how to get up once they have fallen.

To perform the DNS core exercise, begin by lying on your side while placing one hand in front of the other (Fig. 16, A). Next, while keeping your knees in contact with the ground, raise your hips off the floor (B) and try to distribute weight equally between your down shoulder and your outer hand (C). Once you're in this position, raise the upper hip so your knees are separated by about 6 inches (D). You then roll your upper body slightly forward (E) (which places more weight on the outer hand) while simultaneously flexing and extending the top hip (F). After flexing and extending the top hip 10 times, you bring the upper knee towards the outer hand (in this case the left hand), which will initiate a rolling action that allows you to easily get into a crawling position. You then roll over and repeat this exercise on the opposite side.

This exercise duplicates the movement patterns that 6-month-old infants use when first learning to roll over (48). You should do 2 sets of 10 repetitions on each side. In addition to strengthening the core, DNS core exercises also strengthen the pelvic floor (49), which is important as pelvic floor weakness is a predictor of falls (50). As with all of the exercises, if you have difficulty doing all of the repetitions, just do a few and gradually progress over time.

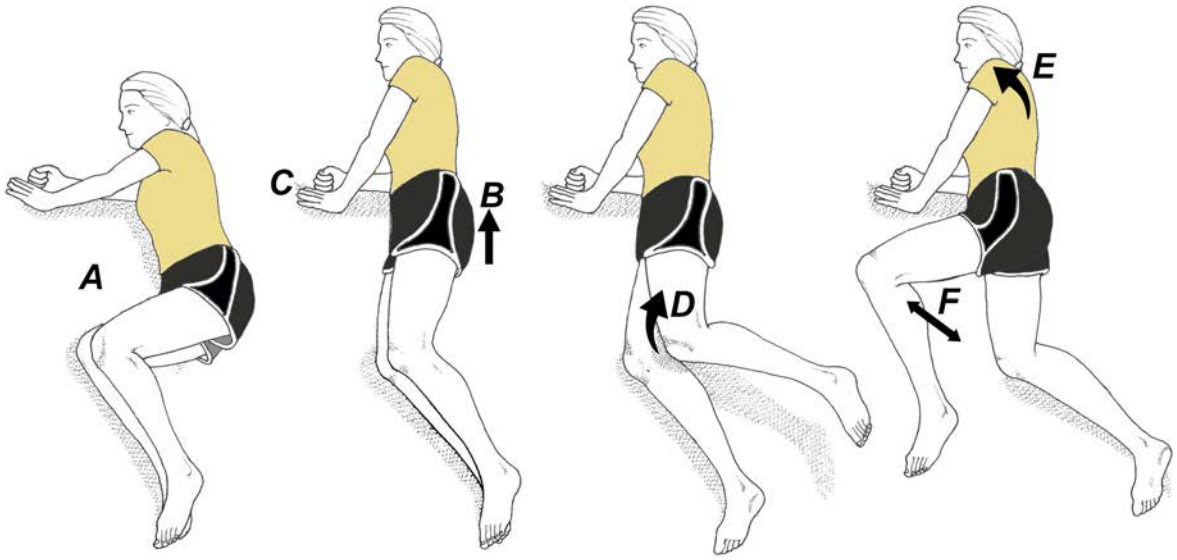


Fig. 16. The DNS Core Exercise. Although this exercise looks complicated, it becomes relatively easy to do with a little practice. You begin by getting in a side-lying position (**A**) and raise your hips up (**B**), distributing pressure between your right shoulder and your left hand. If your down shoulder is weak or painful, you can offload it by pushing down harder with your outer hand (**C**). Next, raise the upper hip to separate your knees approximately 6 inches (**D**). You then roll your upper body slightly forward (**E**) while alternately flexing and extending the top hip (**F**). After flexing and extending the top hip 10 times, you bring the upper knee towards the outer hand (in this case the left hand), which will initiate a rolling action that allows you to easily get into a crawling position. You then roll over and repeat this exercise on the opposite side. The DNS core exercise can be done every day, but it's most often performed 4 times per week. Because this exercise requires less hip and knee flexion than other methods of getting off the ground, it is often the preferred floor-to-stand technique for people with arthritis. Note that it can be difficult for people to do this exercise if they are weak in their hips, shoulders, and/or core muscles, and if that is the case, these muscles should be strengthened individually. The standing clamshell and the curtsy step ups are great for strengthening the hips and the beginner's side bridge is an easy way to strengthen the core. A series of safe shoulder exercises can be found in the rotator cuff article available on the humanlocomotion.com website.

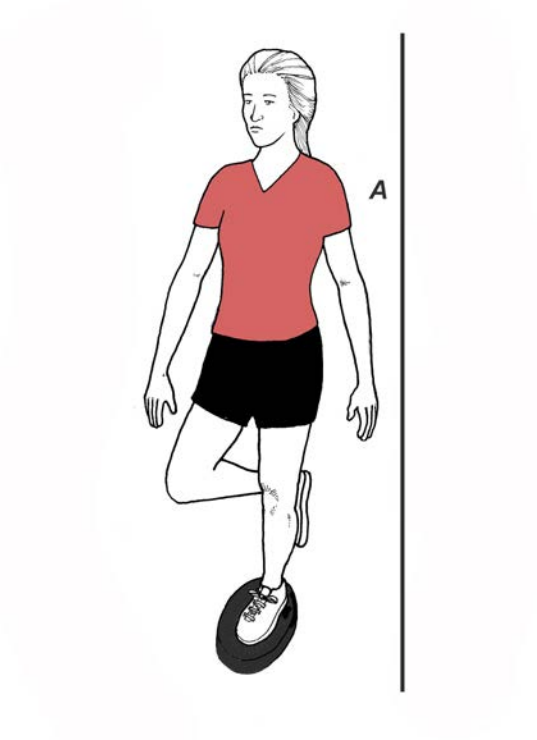
Balance Tests

10-Second Balance Test: In a 12-year study of more than 1,700 older adults, the ability to successfully balance on one foot with eyes open was strongly correlated with longevity (51). In fact, individuals who were unable to maintain balance for 10 seconds after 3 tries had an 84% higher risk of all-cause mortality, even when adjusting for other risk factors, such as heart disease, high blood pressure, and obesity. This simple test is performed by standing barefoot on one leg while attempting to balance with eyes open for 10 seconds. To ensure consistency, you have to keep your arms at your sides with your elbows straight and your eyes fixed on an eye-level point that is about 6 feet away. To reduce compensatory movements, you can place the top of the non-support foot on the back of the weight-bearing leg as naturally as possible. (Fig. 17). Once you're in this position, you have 3 chances to complete a 10-second single-leg balance. You are classified as either yes or no depending upon your ability to complete the test. Of the 1702 older adults involved in the study, 20% were unable to maintain balance and 7 years later, 18% of that group had died. In contrast, only 5% of the people who were able to maintain balance had passed away. The average age at the start of this study was 62. The authors state that "unlike aerobic fitness, muscle strength and flexibility, balance tends to be reasonably preserved until the sixth decade of life, when comparatively, it starts to diminish quickly."

Fig. 17. The 10-Second Balance test. You perform this test while barefoot and you get 3 chances to see if you can balance 10 seconds with your eyes open. Oddly, this very accurate test predicts longevity.

My favorite way to improve balance is with the McHugh protocol (52). Developed by an orthopedic surgeon to prevent ankle sprains in college football players, this simple exercise is performed by standing on one foot while balancing on a foam platform for 5 minutes (Fig. 18). You keep your sneakers on and your eyes open while balancing. At first, you'll be touching the ground for support every few seconds. Over time, it gets easier, and you will feel the important role your hip muscles have in maintaining balance as the outside of the weight-bearing hip begins to burn in a minute or two. Although the football players in the original protocol performed this exercise for 5 minutes on each leg daily, I've noticed that the vast majority of people over the age of 40 get the same improvements in balance when they do this exercise for just 3 minutes on each leg. Even in that short period, you'll still feel the burn in your hips and ankles and the reduced length of time improves compliance.

Fig. 18. The McHugh Protocol. This simple exercise is performed by standing on one leg (sneakers on) with the shoulder on the side being exercised positioned near a wall (**A**). The wall can protect you should you fall sidewards. To do this exercise, set a timer for 3 minutes and with your eyes open, try to maintain balance on the foam pad. The specific foam pad used in this protocol is softer than most, making the exercise more difficult than the original McHugh protocol, which was done for 5 minutes. Because this exercise is so challenging, touch the ground as often as necessary, and you can even take a brief break should you become fatigued. Over a period of weeks, you will touch the ground less often as your strength and balance improve.



Cutaneous Sensation: Like vision and hearing, an important yet underappreciated sensory system that worsens with age is the ability of cutaneous receptors located in the skin along bottom of our feet to accurately sense pressure (Fig. 19). This is a big deal because information supplied by these tiny receptors plays a huge role in keeping us upright and balanced as they supply a rich source of sensory information that allows us to constantly track the location of our balance point (a.k.a., center of pressure).

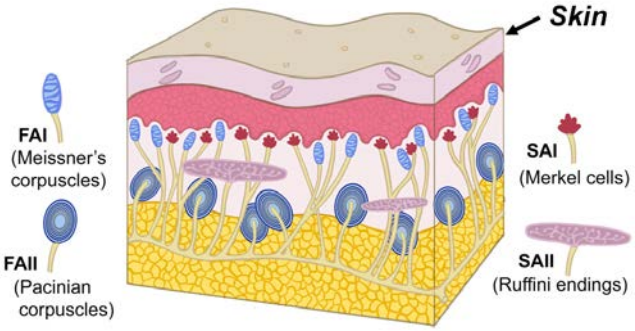


Fig. 19. The bottoms of our feet are richly endowed with 2 types of slow adapting (SA) and fast adapting (FA) sensory nerves that play a key role in maintaining balance while we are upright.

If the center of pressure veers off too far or too fast in one direction, a reflexive muscular response brings us back to a safer balance point (Fig. 20). Unfortunately, as we age, the receptors in the bottom of our feet become less sensitive. By the time you turn 50, it takes 20% more pressure to stimulate cutaneous receptors in the soles of your feet, and when you're 80, it will take 75% more pressure to stimulate the same receptors (53).

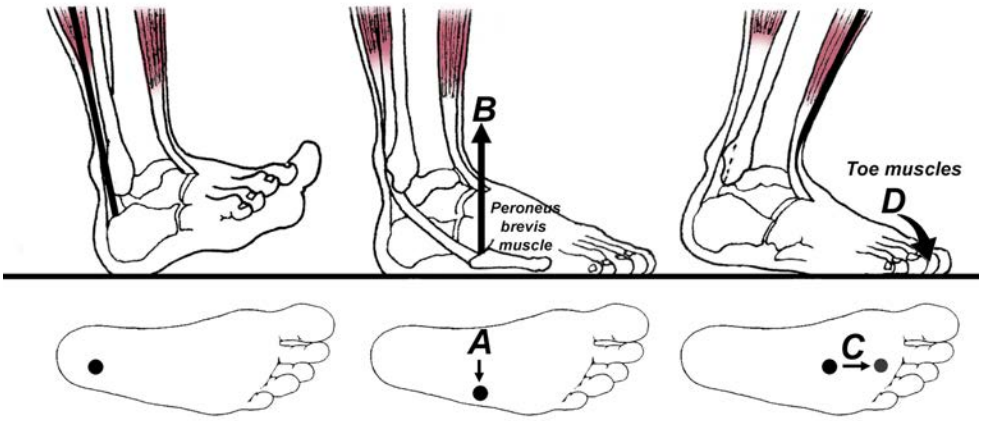


Fig. 20. If your center of pressure goes too far to the side (A), the peroneus brevis muscle contracts to move your balance point inwardly (B). Conversely if your center of pressure moves forward too rapidly (**C**), your toe muscles contract to protect you from a forward fall (**D**).

For decades now, researchers have attempted to reduce the risk of falling in people with impaired balance by stimulating the various cutaneous receptors with specially designed textured insoles. These insoles are typically made with a series of ridges or elevations that theoretically improve balance by activating the cutaneous receptors. The problem with the vast majority of textured insoles is that almost all of them attempt to stimulate the entire foot, which can have negative consequences as the muscular response to pressure along the bottom of the foot varies depending upon the location of the stimuli. For example, stimulating the skin under the inner forefoot produces a reflex downward contraction of the toe muscles (which could improve balance), while stimulating the skin beneath the arch has the opposite effect in that it causes the toes to move upward, which would worsen balance (54).

Until recently, no one could figure out why there was such a site-specific variation in the muscular responses to textured insoles. In 2018, researchers from Canada used a special technique called microneurography that allowed them to map the location of thousands of individual sensory receptors (55). Using this advanced technique, they determined the overwhelming majority of cutaneous receptors are located in a small pathway along the outer sides of our feet. The abundance of sensory receptors along the lateral foot makes perfect sense when you look at the progression of the center of mass while walking (Fig. 21, A). Because we spend so much time with our weight distributed over the outside of our foot, it is important that region of the foot has the ability to provide the greatest amount of information in order to allow us to respond immediately to even minor perturbations that may affect balance. The plethora of cutaneous receptors located along the lateral foot also helps to prevent lateral falls, which require a complex cross-over movement from the opposite leg that is difficult to perform and nearly impossible to recover from once initiated. In fact, a recent paper published in the *Journal of Biomechanics* demonstrated that seniors who are most likely to fall have greater sidewards displacement of their center of mass while initiating their first step while walking (56). Besides greatly increasing the risk of hip fractures, lateral falls are more likely to result in serious injuries that often require hospitalization.

Fig. 21. Location of the vast majority of cutaneous receptors in the bottom of our feet. Notice how these cutaneous nerves are positioned along the pathway our center of mass moves while we are walking (**A**).

Rather than putting a textured insoles along the entire bottom of the foot, you can preferentially stimulate the cutaneous receptors along the outside of your foot with a product called *Balance Buttons*. As illustrated in figure 22, this product is designed with a series of small elevations that get gradually larger as you move laterally, which increases feedback should your center of pressure move too far to the outside of your foot: the farther your foot moves towards the dangerous lateral zone, the more you feel the larger elevations pushing into your skin. Even people with various nerve injuries, such as spinal stenosis and/or peripheral neuropathy, report improved balance while wearing *Balance Buttons*, as the pads are thick enough to slightly lift the outer side of the foot, pushing weight away from the dangerous lateral zone.

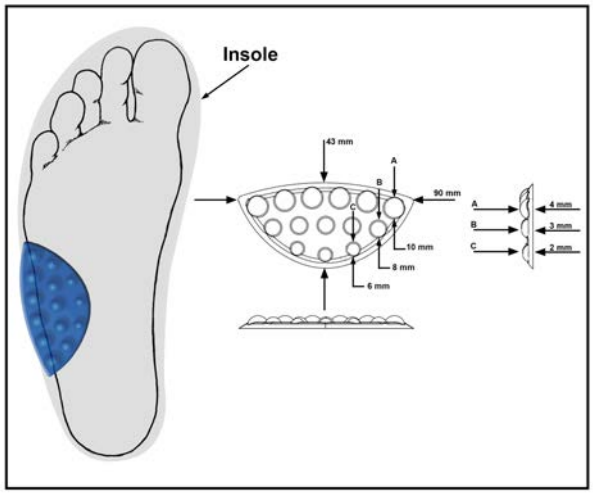


Fig. 22. *Balance Buttons* are positioned on top of the insole with the outer edge hanging slightly off the side of the insole. Note how the elevations on the *Balance Buttons* get progressively larger as you move laterally, which are designed to increase feedback from cutaneous receptors as the center of pressure moves too far to the outer side of the midfoot. Stimulating this precise location is key for improving balance and preventing lateral falls.

Because even subtle nerve injuries can impair sensation from the cutaneous receptors and increase the risk of falling, anyone who has difficulty balancing should check to make sure their sensory nerves are working properly. Even minor injuries such as ankle sprains can overstretch sensory nerves and impair balance. The easiest way to make sure your sensory nerves are working properly is to place a 256 cps

tuning fork over the bottom of the heel: people with impaired sensation feel pressure from the tuning fork but not the vibration (57) (Fig. 23). If for any reason you are unable to feel vibration from the tuning fork, in addition to using *Balance Buttons*, you should begin a toe/foot strengthening program, as the increased circulation associated with strengthening exercises has been shown to increase cutaneous nerve fiber branching and reduce pain, even in people suffering with diabetic peripheral neuropathy (58). People with impaired sensation should also consider getting their feet massaged and/or using various foot rollers, as having your feet massaged for just 5 minutes has been shown to improve balance, while having the joints of your feet mobilized can improve agility (59). After 3 months, you should repeat the tuning fork test as it is not uncommon to have improvements in sensation as the cutaneous nerves regenerate.

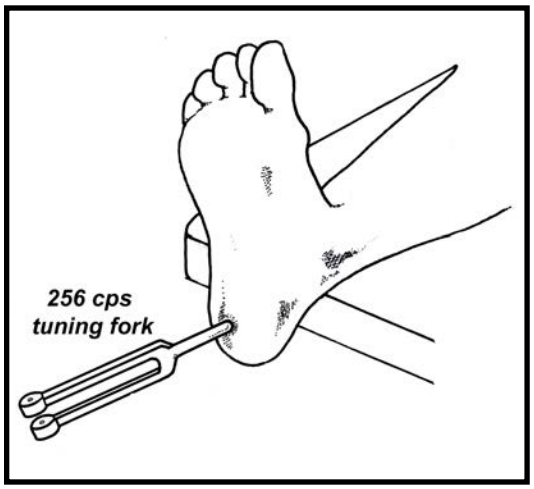


Fig. 23. Testing sensation with a 256 cps tuning fork. To check sensitivity of the cutaneous nerves, you have the person lie face up on a table with their eyes closed while you tap a 256 cps tuning fork on the side of your knee and place the butt over the bottom of the heel. You then say: "Tell me if you feel vibration from the tuning fork or just pressure from the butt of the tuning fork without any vibration." You repeat this test 3 times, and alternate whether or not you tap the tuning fork to produce vibration. If they are incorrect two out of three times, the test is positive as the person has impaired sensation. In an interesting study of different ways to identify balance deficits in people with low back nerve injuries, Frost et al. (60) demonstrate that the 256 cps vibration test is more accurate at identifying impaired balance than the more commonly used and expensive Semmes-Weinstein monofilament tests. Apparently, cutaneous receptors are very sensitive to 256 cps vibration (61), explaining why this test so accurately identifies individuals with balance problems.

The Near Tandem Stand Test: I've included this as a separate test because it specifically evaluates your tendency to fall laterally (62). To perform this test, take your shoes off and stand with your feet parallel with one foot in front of the other so that the heel of the front foot is 1 inch in front of the big toe of the back foot and 1 inch to the side (Fig. 24). Now, close your eyes and see if you can balance for 10 seconds (you should always have someone standing next to you when you perform this test). If you open your eyes and/or move either foot to regain balance, you fail this test.

In addition to doing the McHugh protocol and/or wearing *Balance Buttons*, one of the most effective ways to improve performance on the near tandem stand test is with the rotational ankle exercise illustrated in figure 25. To do this exercise, place an ankle cuff with an elastic band around your ankle, and secure it to a stable structure, such as a table leg or a workout bench. Next, stand on the opposite leg and slowly move the leg with the ankle cuff back and forth, tapping the ground to maintain balance at the most forward and backward points (Fig. 25, A and B).

Fig. 24. The Near Tandem Stand Test.

Position yourself so you are standing with your heel 1 inch in front of the big toe of the back foot and 1 inch to the side of the back foot. You can choose which foot you place in the front. Once you feel comfortable in this position, close your eyes and see if you can balance for 10 seconds without taking a step or opening your eyes. The time in seconds that you are able to stand in this position is the final score. If you are unable to stand for 5 seconds on your first attempt, you get to do the test again.

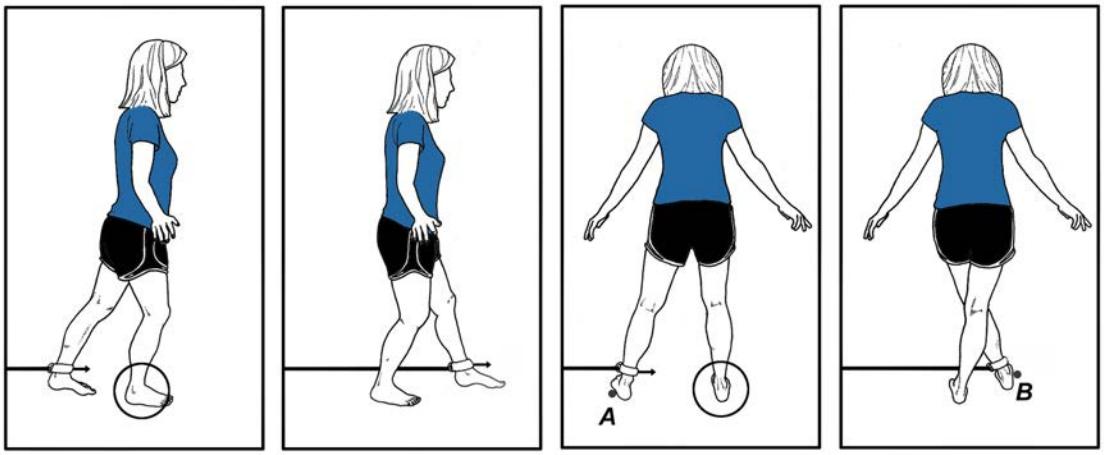


Fig. 25. The Rotational Ankle Exercise. An elastic band is placed around the non-weight-bearing ankle as you stabilize yourself on the ankle that is being exercised (**circled**). When you first begin doing this exercise, hold onto a stable structure for support and begin moving the non-weight-bearing ankle back and forth. Because this exercise is difficult at first, tap the ground at the start and stop of each movement to maintain balance (**A** and **B**). As you improve, you can touch the ground less often and you can progress to the point that the off weight-bearing foot does not contact the ground. Because this exercise is more for balance than strength, you can use a relatively weak elastic band. Do 10 repetitions then rotate your body 90° and repeat in all 4 directions. This exercise helps prevent falls when changing directions as it teaches you how to manage twisting forces. You should do the rotational exercise 4 times per week.

At first, it will be difficult to maintain balance but as you improve, you can just tap the ground less often as your balance improves. Once you feel stable, you can move the foot with the elastic band forward and backward without making ground contact. You do 10 repetitions of this exercise and then rotate 90° and repeat the exercise for 10 more times. This is done in 4 different positions and then repeated on the opposite leg. Because this exercise can be difficult at first, make sure you are near a stable object that you can hold onto if necessary. Also, don't hesitate to touch the ground if you feel you are losing balance.

Range of Motion Tests

Ankle Flexibility: To stay upright while walking and running, it is important you have specific minimum ranges of motion in your feet and ankles. In addition to allowing us to walk with longer strides, flexible ankles allow us to accommodate discrepancies in our walking terrain (such as cobblestones and/or other uneven surfaces). Several studies have shown that limited upward motion of the ankle correlates with an increased risk of falling (63-64), and people with stiff ankles tend to walk with slower, shorter steps (65). In an interesting study of the connection between calf tightness and falls, researchers from the University of Queensland measured upward motion of the ankle in 372 women between the ages of 40 and 80 and tested the connection between prior falls and ankle mobility (63). The authors showed that there was a steady decline in the range of motion between the ages of 40 and 70, and that subjects who had fallen more than twice in the previous year had at least 8° less range compared to non-fallers irrespective of age. Other studies have shown that limited upward motion at the ankle is especially likely to cause a fall while going up and down stairs (66).

It's not just limited upward motion at the ankle that's problematic. In a comprehensive study of factors associated with falls in 305 older adults, Spink et al. (67) demonstrated that besides weakness of the big toe (which was the biggest predictor of falls) limited inversion/eversion of the ankle was a consistent and independent predictor of balance and functional performance.

It is possible to measure both your ankle dorsiflexion and your total range of inversion/eversion with the standard iPhone (Fig. 26). Ideally, you will possess at least 34° of ankle dorsiflexion and 25° of inversion/eversion. If you have limited ankle dorsiflexion, you should do the prolonged static stretches

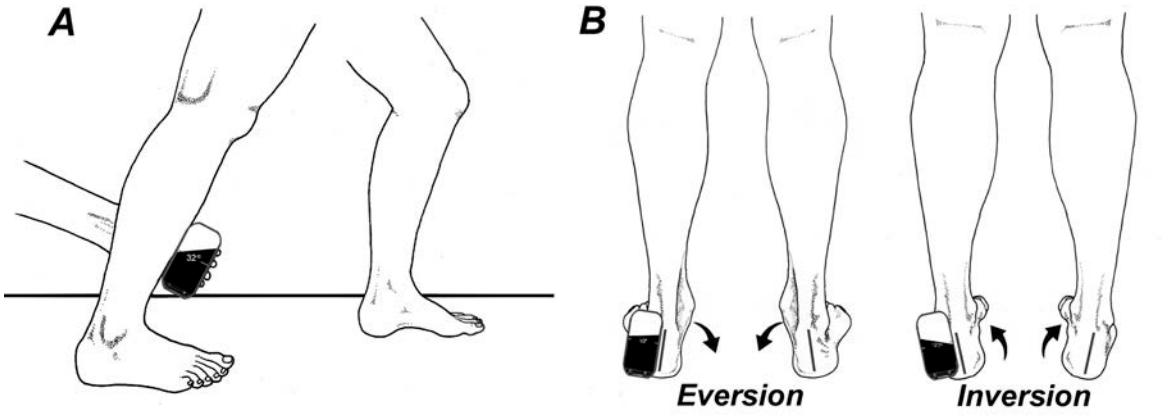


Fig. 26. Measuring ankle range of motion with your iPhone level. To turn the iPhone level on, press the "Utilities" icon, then press "Measure," then press "Level." To measure upward motion at the ankle, maximally stretch your calf while you are in a forward lunge position and have someone place the iPhone level against the front of your leg (**A**). You should have at least 34° of upward motion at the ankle. To measure inversion/eversion, have someone use a pen to bisect the back of your heels and measure the position of this line with your foot fully inverted and then everted (**B**). The difference between these measurements should be at least 25°.

illustrated in figure 27. It is especially important for older women to stretch their calves, as women tend to have greater age-related reductions in calf flexibility than men (68). Although most studies suggest that stretching is a relatively ineffective way to lengthen muscles, new research confirms that when stretches are held for longer periods of time, the stretched muscle not only gets longer, it also gets stronger (69). This is consistent with research out of Iran (70) showing that performing just 4, 60-second straight leg calf stretches daily for 4 weeks results in significant improvements in side-to-side balance in elderly women, which could appreciably reduce the risk of lateral falls.

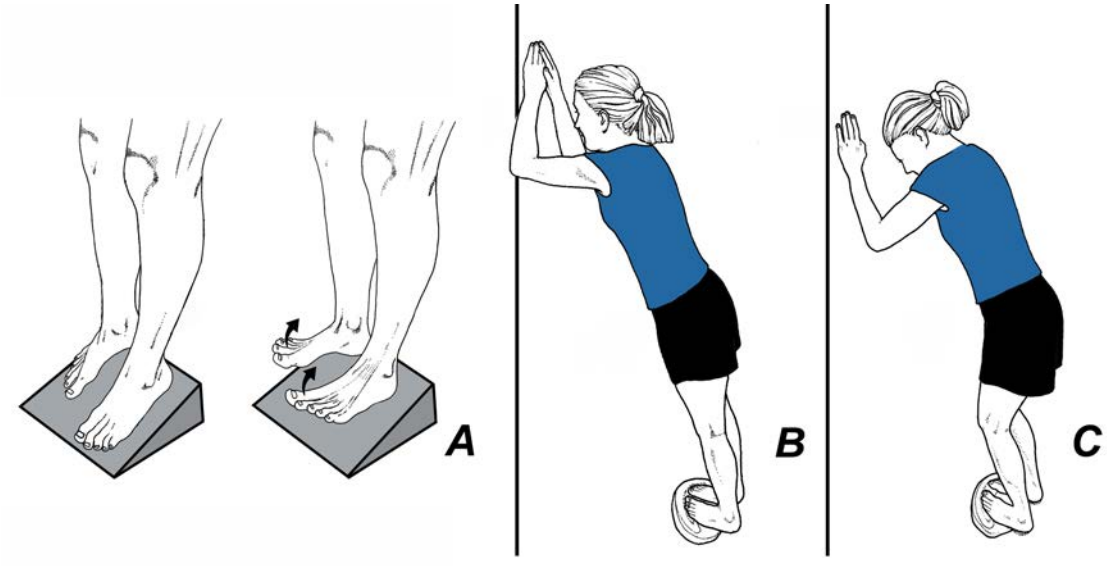


Fig. 27. Prolonged static stretches to increase ankle dorsiflexion. Before doing these stretches, place your heels on the high part of a ToePro or slant board and do toe raises until you are slightly fatigued (**A**). Fatiguing the muscles in the front of the leg temporarily inhibits the muscles you're about to stretch, making it easier to lengthen them. To stretch the back of the calf, stand on a ToePro or a slant board and lean forward with your knees straight for 60 seconds (**B**). Rest for a few seconds and repeat this stretch for another 60 seconds with your knees bent (**C**). Rest for another few seconds and repeat the stretches in figures **B** and **C** for 60 seconds each, but this time perform both stretches with your feet pointing in slightly. Pointing your feet in stretches the inner calf (the medial gastrocnemius muscle), which plays an important role in maintaining static and dynamic balance, so it is especially important to keep this muscle strong and flexible. This stretching routine should be repeated daily.

While stretching is the best way to improve ankle dorsiflexion, the easiest way to improve inversion/eversion is by using the *Two-to-One Ankle Rockboard*. Unlike conventional rockboards that move 16° in each direction (which is too far in one direction and not far enough in the other), this device is designed to force your foot to invert 18° and evert 9°, which is the typical range of motion present in middle-aged adults. To use this device, place it next to a wall and position your entire foot over the roughened strip with your arch pointing towards the longer side of the board (Fig. 28). While keeping your knee and hip straight, rotate the board through a full range of motion, performing 60 clockwise rotations with your left foot, then 60 counterclockwise rotations with your right foot.

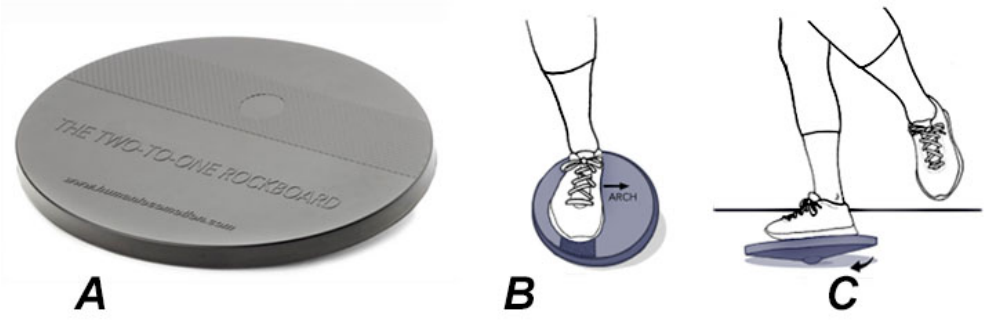


Fig. 28. The *Two-to-One Ankle Rockboard* (A). Place your foot over the abrasive strip so your arch points towards the long side of the board (**B**). Next, while keeping your hip and knee straight, use your ankle to rotate the rockboard so the edges touch the ground on all sides (**C**). With a little practice, you should be able to perform 60 clockwise rotations with your left foot, then 60 counterclockwise rotations with your right foot.

As you get stronger, you can do the rockboard with your forefoot stabilized over the center of the ball, which not only increases the range of inversion and eversion, it also appreciably strengthens the inner and outer calf muscles. Because rockboard exercises can tighten your calves slightly, you should perform a few 30-second straight and bent-knee calf stretches after finishing the rockboard workout.

Limited Spinal Motion: It seems odd, but in order to remain stable while walking, it is important that your head remain relatively stationary as you walk and move about. In an interesting evaluation of head motions associated with walking on varied terrain, Menz et al. (71) demonstrate that although our hips and pelvis accelerate forward and backward while walking on irregular surfaces, head movements remain relatively unchanged. The authors state that "one of the primary objectives of the postural control system when walking on irregular surfaces is head control, and that subjects adapt their stepping pattern on irregular surfaces to ensure that the head remains stable." They suggest elderly people might be more prone to falling because of an inability to maintain smooth head motions while walking.

Your doctor can easily measure your neck range of motion with a device called a goniometer. This is an electrical device that attaches to your head and allows you to quantify range of rotation within a degree. If your doctor does not have one, or you would just like to approximate your range of neck rotation at home, lie face down on a bed and turn your head to the left as far as you comfortably can so you're resting on your cheek. Now do the same thing in the other direction. If you can turn your head much farther in one direction than the other, or if you can't rest your cheek comfortably on the bed, you probably have limited neck mobility, and you should do the stretches illustrated in figure 29.

To improve motion in the mid back, which is also important in stabilizing head motions, perform the stretch illustrated in figure 30. Besides gradually improving your balance, stretching your neck and back for just a few minutes each day will make it easier to turn your head while walking without rotating your entire upper body (which increases your fall risk). Increasing your range of neck rotation will also make it easier to look behind you when you are backing out of your driveway, which I'm sure your neighbors will really appreciate!

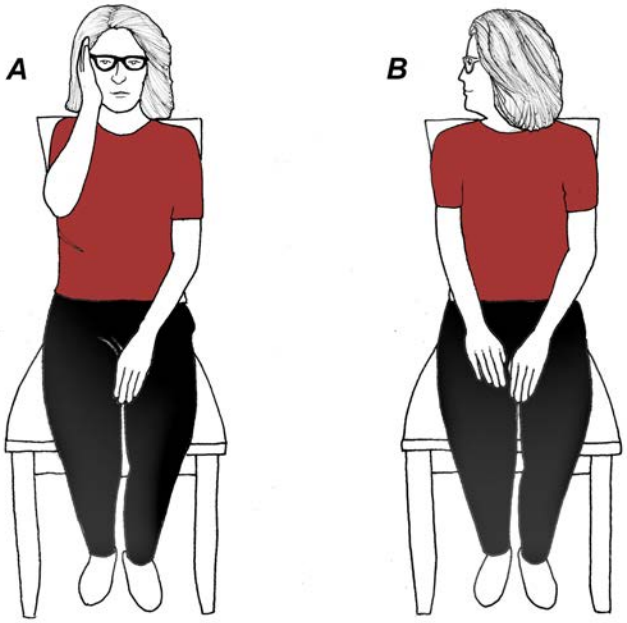


Fig. 29. An easy stretch to improve neck mobility. While sitting in a chair facing forward, place your hand against your right cheek and turn your head to the right while your hand provides enough resistance that your head remains still (**A**). You should hold this isometric contraction for 5 seconds while using a moderate amount of force (about 10 pounds of pressure). Next, turn your head to the right as far as it will go and hold that end position for 10 seconds (**B**). Repeat this going in the opposite direction and perform the stretch 4 times per day in each direction.

Fig. 30. Stretching your mid back. While seated, grasp the back of the chair and pull yourself so your upper back rotates as far as it possibly can (**arrow**). Hold this position for 30 seconds and repeat in each direction 4 times.

Foot Architecture

Given the fact that the only connection between ourselves and the ground when we fall is our feet, it's surprising how little research has been done evaluating the connection between foot architecture and falls. In 2017, researchers from the *Institute for Aging Research* teamed up with some of the most respected fall researchers in the world and conclusively proved that people with flat feet are significantly more likely to fall (72). By evaluating the fall rate in 1375 people between the ages of 40 and 98 (average age of 69 years), these researchers demonstrated that compared to people with neutral and high arches, people with flat feet were nearly twice as likely to have 2 or more falls in the prior 12 months. The higher fall rate in people with low arches came as no surprise, as several prior studies have shown that people with low arches have impaired balance (73,74) and are therefore more likely to fall.

The most accurate way to evaluate arch height is with the Arch Height Ratio Device (Fig. 31). This easy-to-perform test creates a ratio between foot length and arch height that correlates exactly with x-ray measurements of the foot. People with low arches have a height to length ratio less than .275. An alternate method to evaluate foot architecture is to measure the distance the ankle rolls in when moving from a midline to a flat-footed position (Fig. 32). People with high arches roll inward between 0 and 5 mm, while people with neutral arches roll in between 5 and 10 mm. In contrast, people with low arches will roll in more than 10 mm, with some people rolling in as much as 22 mm. The excessive inward roll stretches muscles and ligaments, making it more difficult to balance while standing as the overstretched muscles become mechanically inefficient.

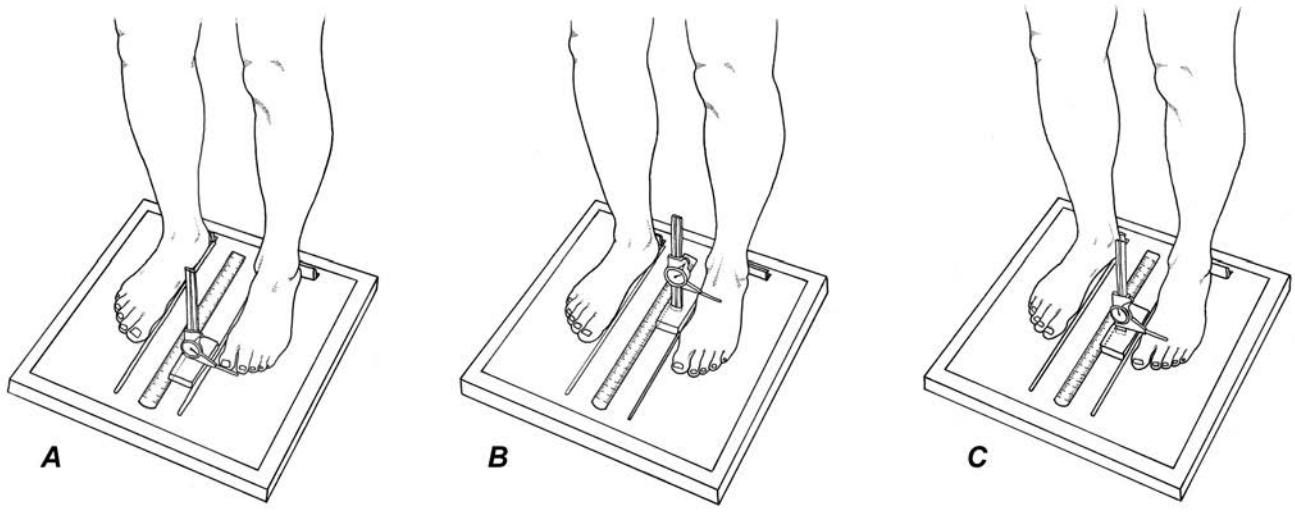


Fig. 31. The Arch Height Ratio Device. This test is performed by measuring the length of the foot from the heel to the tip of the big toe (**A**). This number is divided by 2 and the height at the top of the arch is measured at this point (**B**). The arch height ratio is determined by dividing the arch height number by the length of the foot measured at the big toe joint (**C**). If the resultant number is less than .275, the person has a low arch.

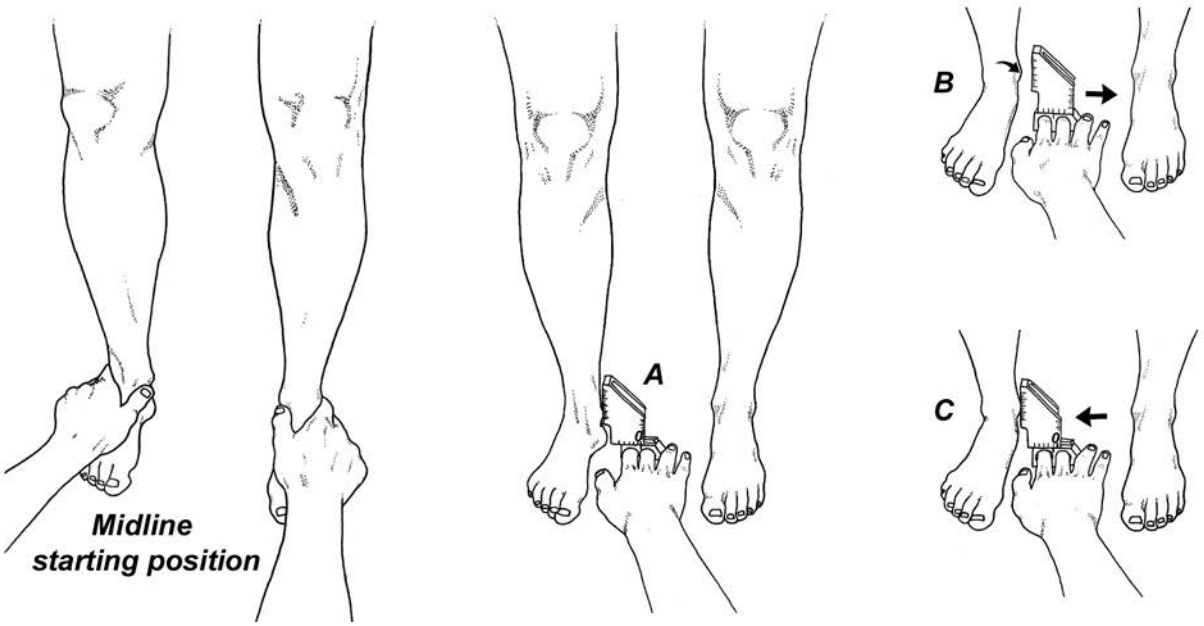


Fig. 32. Medial drift of the medial malleolus. To do this test, the person's foot is placed in a neutral position and the measuring device is placed next to the inner ankle bone (**A**). The top of the device is moved away (**B**) and the person being tested then relaxes and rolls in to a comfortable position (arrow near **B**). The top device is then moved back to the new resting position (**C**) and you record the number of millimeters the foot has rolled in from the starting point.

If you don't have access to someone familiar with taking these measurements, the easiest low-tech way to evaluate arch height is to look at your footprints when you get out of the shower: compared to people with neutral and high arches, low-arched people make more ground contact beneath the center of their arch (Fig. 33). Although not as reliable as in-office testing, footprints give you a pretty good idea of whether or not you have flat feet.

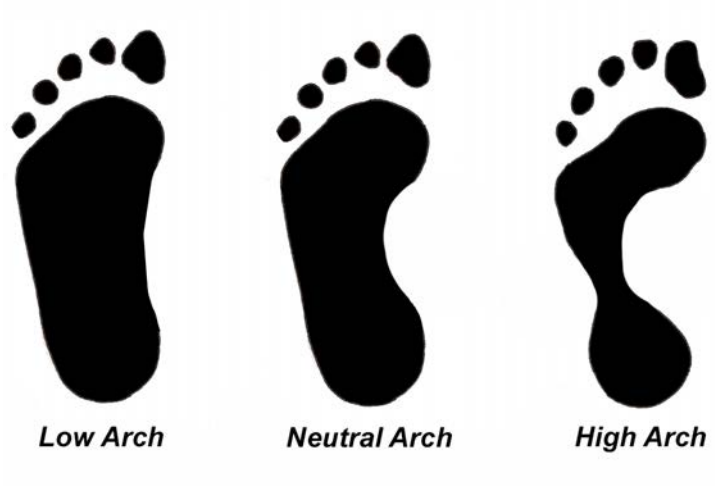


Fig. 33. Footprints based on arch height. Notice how the midfoot in high-arched people makes significantly less ground contact than the midfoot in low-arched people.

Far and away the most common treatment for people with flat feet is to support their fallen arches with either custom or over-the-counter orthotics. Although comfortable, several studies have shown that excessive support of the arch can weaken your toe muscles (75,76). One recent study from Canada (76) showed that compared to a control group who did not wear orthotics, people who wore orthotics for 12 weeks had 17% atrophy of the abductor hallucis muscles and 10% atrophy of their flexor digitorum brevis muscles (Fig. 34). Given the strong connection between toe weakness and falls, it's clear that orthotics should only be prescribed if they are given in conjunction with foot exercises.

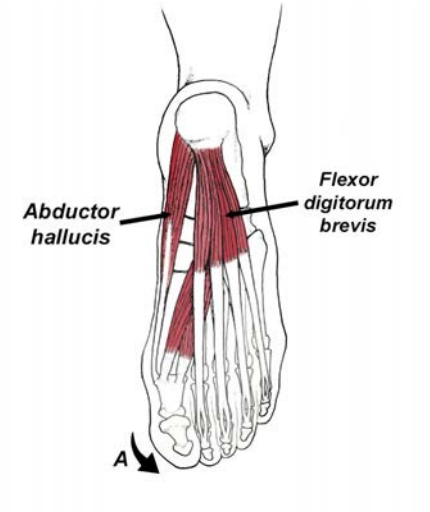


Fig. 34. Orthotic use has been shown to cause significant atrophy of abductor hallucis and flexor digitorum brevis muscles. Abductor hallucis weakness has been shown to correlate with the development of bunions (**A**) (77), while atrophy of flexor digitorum brevis is associated with chronic heel pain (78) and the formation of hammer toes (79).

An inexpensive alternative to orthotics is to prescribe *Peel and Stick Varus Posts* (Fig. 35). These posts have all the benefits of orthotics but because they do not support the arch in any way, there is no risk of inadvertently weakening the arch over time. Several high-quality studies have shown that varus posts can decrease the rate and range that your feet roll in (80), favorably modify movement at the knee (81), and significantly lessen stress on the muscles responsible for controlling pronation (82). Two-piece varus posts also have the ability to reduce strain in the plantar fascia (83), which is a common injury that can impair balance (72).

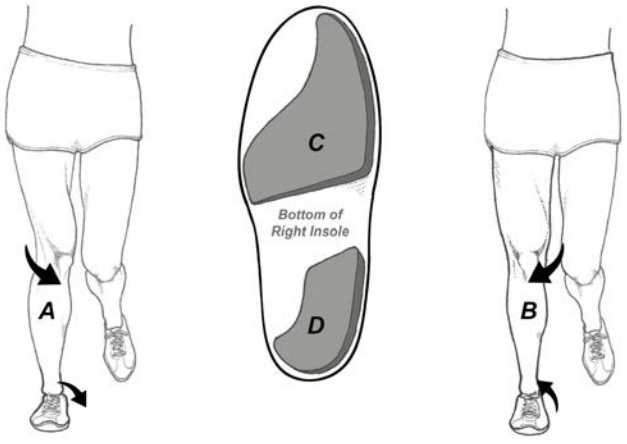


Fig. 35. Varus Posts are angled wedges that lift up the inner heel and forefoot. By lifting the inside of the foot, these posts reduce the range and speed the arch drops, and lessen inward rotation of the knee (compare **A** and **B**). The 2-piece *Peel and Stick Varus Posts* are applied beneath the forefoot and rearfoot (**C** and **D**) and do not support the arch. A video reviewing exactly how to position the posts is available at www.humanlocomotion.com.

Unfortunately, low arches are not the only architectural foot problem that can predispose you to falling. In 2018, researchers from Australia reviewed over 140 studies documenting fall risks in older adults and determined that people with bunions are 1.9 times more likely to fall than people without bunions, and people with hammer toes are 1.7 times more likely to fall than people with straight toes (84). The higher fall rates in people with bunions and hammer toes has everything to do with the fact that people with bunions and hammer toes are unable to adequately generate force beneath their toes. To improve force generation beneath the toes, people with bunions should perform toe strengthening exercises while wearing toe separators, and people with hammer toes should wear toe crests while walking and exercising (Fig. 36). Although there are a lot of commercially available toe separators, I typically recommend that people with large bunions learn to make their own custom toe separators with a product called Pediplast. There is a video on the humanlocomotion.com website that goes over exactly how to make your own toe separators. I typically have people make one smaller toe separator that they wear while exercising, and a larger one that they wear while they sleep. Research out of Thailand shows that it is possible to appreciably reduce the overall size of a bunion by sleeping with a night brace made out of Pediplast (85).

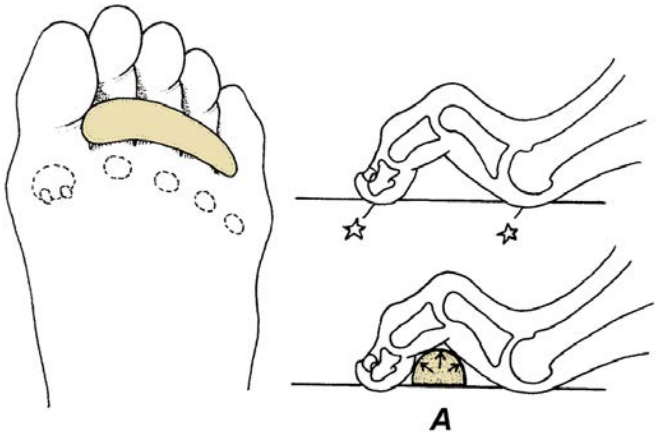


Fig. 36. By supporting the entire toe (A), toe crests reduce pressure beneath the metatarsal heads and the tips of the toes (stars).

Because people with bunions and hammer toes almost always have weak toe and arch muscles (79,77), it is important to assess toe strength with the toe strength dynamometer and perform ToePro exercises until you can generate 10% of your body weight beneath your big toes and 7% of your body weight beneath the lesser toes. One recent study demonstrated that low-arched people who have strong feet are less likely to report pain than low-arched people with weak feet (86). The authors of this study emphasize that strengthening foot muscles may prevent people with low arches from getting injured. It is especially important to strengthen the toe muscles in people with hammer toes, as weakness of these muscles plays a huge role in the development of hammer toes (79).

It should be emphasized that because hammer toes often cause extreme toe weakness, rather than using the ToePro, I have people with weak hammer toes exercise by placing an elastic band beneath the bottom of their foot so it wraps up under the second through fifth toes (Fig. 37). They then push their toes down into the elastic band, keeping the toes as straight as possible. Because the band provides so little resistance, it allows you to more effectively activate your toe muscles as they move through large ranges of motion with little effort. As your toe strength improves, you can start doing more aggressive strengthening on the ToePro. Because once formed, hammer toes are nearly impossible to reverse, it's good to start strengthening your toes in your twenties and thirties before the hammer toes become too rigid to reverse. The same goes for bunions, as research shows that weakness in the abductor hallucis muscle occurs early in the development of bunions, and strengthening this important muscle when you're young may delay the progression of a bunion (77).

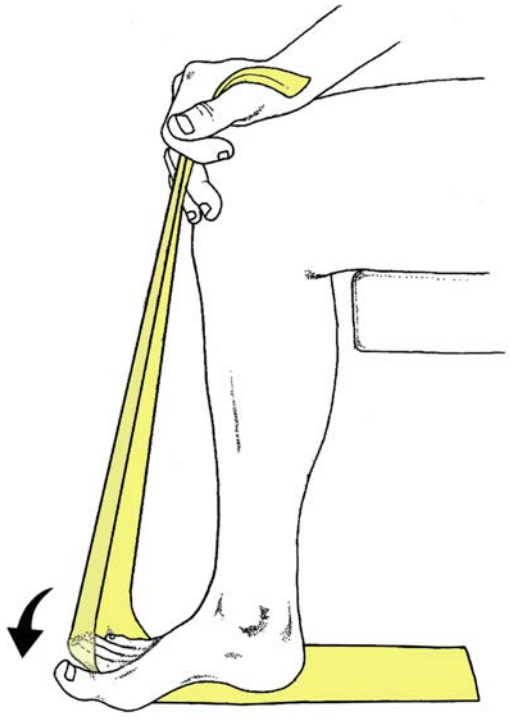


Fig. 37. Elastic band exercises for people with hammer toes. While seated, place an elastic band beneath bottom of your foot while holding the opposite end with your hand. Tension in the band is determined by the pulling force at the knee and you can easily strengthen the second through fifth toes by pushing down into to the band with your toes (**arrow**).

Evaluation Results

Name: _____ Date: _____

Test:	Range:	Result:
Anterior Reach Distance: Measured from umbilicus to wall pre and post forward lean	4.5 inches	_____ inches
Strength beneath big toe:	10% BW	R _____ L _____
Strength beneath toes 2-5:	7% BW	R _____ L _____
Heel-Raise Metronome Test:	See Fig. 7 for ranges	R _____ L _____
Sit-to-Stand Test:	5 times in 10 secs 50-60, 11.4 secs 60-70, 12.6 secs 70-80, and 15 secs 80-90.	_____ seconds
Alternate Step Test:	8 steps in 10 seconds or less (12 secs if over 75)	_____
Hip Rotation Strength:	20% BW	R _____ L _____
Core Strength:	45 seconds	R _____ L _____
10-Second Balance Test:	Pass/Fail	R _____ L _____
256 cps Tuning Fork Test: Could feel 2 out of 3 tests	Pass/Fail	R _____ L _____
Near Tandem Stand Test: If first try less than 5 secs, repeat test.	10 seconds Pass/Fail	_____ seconds
Range of Ankle Dorsiflexion:	34°	R _____ L _____
Range of Inversion/Eversion:	25°	R _____ L _____
Neck Rotation:	75 degrees each direction	R _____ L _____
Foot Architecture: Flat feet, bunions, hammer toes (circle if present)	Medial drift in mm	R _____ L _____

Personalized Interventions Based on Test Results

Check the boxes that correspond with exercises that you should do based on which tests you did poorly on.

☐ **ToePro Exercises:** You need to do this exercise if you did poorly on the anterior reach test, the heel-raise metronome test and/or if you have weak toes. The typical routine is outlined in figures 5 and 6.

☐ **Lateral Step Ups (Fig. 9):** If you scored poorly on the sit-to-stand test, do 2 sets of 15 repetitions of this exercise, 4 times per week. You should also do this exercise if you have difficulty going up or down stairs.

☐ **Metronome Alternate Step Exercise (Fig. 10):** This exercise is performed if you could not do 8 alternate steps in less than 10 seconds. The most common exercise prescription is to do alternate step ups on a 6-inch platform for 30 seconds with the metronome set at the highest pace you can comfortably maintain. Repeat this routine 3 times.

☐ **Hip Strengthening Exercises (Fig. 13):** If you generated less than 20% of your body weight with the hip rotation test, do one set of 60 repetitions of the standing clamshell exercise and follow this with 2 sets of 15 repetitions of both the fencer's lunge and curtsy step up. Do this routine 4 times per week.

☐ **DNS Core Exercise:** This exercise is for people who were unable to hold the beginner side bridge illustrated in figure 15 for 45 seconds. The DNS core exercise is performed by alternately flexing and extending the upper hip while you're in a side bridge position (**Fig. 16**). You may need to strengthen your hips, core, and/or shoulders prior to beginning this particular exercise. A great routine is to strengthen your hips is to do 2 sets of 15 repetitions of the standing clamshell and curtsy step up exercise. You can strengthen your core by holding the beginner side plank exercise for as long as possible. You should repeat this process 3 times holding to the point of fatigue.

☐ **The McHugh Protocol (Fig. 18)**: Because balance deficits occur so rapidly as you age, anyone over the age of 60 should perform this exercise for 3-minutes on each leg daily. It is especially important to do this exercise if you failed the 10-second balance test, 256 cps tuning fork test and/or the Near Tandem Stand Test.

☐ ***Balance Buttons*:** You should be wearing *Balance Buttons* if you were unable to feel vibration from the 256 CPS tuning fork and/or if you performed poorly on the Near Tandem Stand Test. Placement is reviewed in figure 22.

☐ **Rotational Ankle Exercise (Fig. 25):** This exercise is performed if you did poorly on the 10-second Balance Test, the 256-cps tuning fork test and/or the Near Tandem Stand Test. The complete routine is described in figure 25.

☐ **Calf Stretches (Fig. 27):** People with less than 34° of upward motion at the ankle should do the stretching routine illustrated in figure 27. Because flexibility gains are so short-lived, you should do these stretches on a daily basis.

☐ **The *Two-to-One Ankle Rockboard* (Fig. 28):** If you have less than 25° of rearfoot inversion/eversion, you should do the rockboard exercise building up to 60 clockwise rotations with your left foot, then 60 counterclockwise rotations with your right foot. As you progress, considered adding 30 repetitions of the advanced protocol on each foot. You should do this routine 4 times per week.

☐ **Neck and mid back stretches (Figs. 29 and 30):** Perform the stretches illustrated in figures 29 and 30 daily.

☐ **Use the *Peel and Stick Varus Posts*, toe separators, and/or toe crests depending upon your foot architecture.** See figures 35 through 37.

Modifying Your Exercise Routine

Start to finish, if you were to do all of the exercises in the fall prevention protocol, it would take about 35 minutes and if you failed more than 3 of these tests, you should consider doing the entire routine. Fortunately, the majority of people will be able to do abbreviated versions of this routine, in which they target weak points based on their test results. Most of the exercises are done 4 times per week for 12 weeks. After that, you can typically maintain your improvements by doing the workout just once or twice a week. The total time commitment to this fall prevention program is about 3 hours per week and there's a reason for this. In a large analysis of nearly 100 studies involving more than 19,000 participants, Sherrington et al. (87) found that exercise programs that required 3 or more hours of exercise per week had the best overall effect for reducing fall rates in older adults. The researchers also concluded that balance exercises had the greatest effect on reducing overall fall rates.

On certain days, you will not want to do the entire program and that's okay. Several recent studies have shown that it is possible to get the same strength gains associated with high-volume exercises with less intense protocols (88-90). For example, the 4 sets of 25 repetitions used in the ToePro protocol can occasionally be replaced with one set of 30 repetitions performed to the point of fatigue. You can alternate straightening and bending your knee while doing these 30 repetitions. While the 4 sets of 24 repetitions more effectively builds muscle mass, performing one set of 30 when done to fatigue is enough to increase strength.

As you get stronger, you should vary the speed that you do most movements. When you first start doing these exercises, you should do them slowly, spending 2 to 3 seconds going up and 2 to 3 seconds going down with each movement. As you improve, you can do the exercises more rapidly, which reduces the overall time spent exercising and can improve your agility (91). An easy way to accomplish this is to set a metronome at 60 bpm and go up and down with each beat of the metronome.

Because our ability to balance deteriorates quickly after the age of 60, I highly recommend doing the McHugh protocol daily, as balance exercises have been proven to have the greatest effect on reducing overall fall rates in older adults (87). I would also recommend being consistent with the 4 sets of 25 ToePro exercise routine, because the muscles in your feet and legs weaken faster than muscles in your hips and knees, and it takes some effort to keep them strong. Although counterintuitive, after strengthening your toe muscles, you actually have to teach the newly strengthened muscles how to fire while walking and running. To do this, practice pushing off with the tips of your toes while you're walking for five minutes each day. The deliberate action of pushing down eventually becomes an ingrained movement pattern, and the strength gains achieved with the ToePro exercises can be used to improve performance and protect against falls. You can tell if you're effectively using your toe muscles by looking at the insole in your shoe: there should be clear wear patterns under the tips of the toes with minimal imprints under the central forefoot. Most people who are prone to falling have just the opposite: large wear beneath the middle of the forefoot with almost no visible appearance of toe indents.

Remember, keeping your toes strong as you age does a lot more than just protect you from falls, as people with strong toes tend to have less painful feet (86), can run faster (21), jump higher (18), and are less likely to develop a range of different metabolic disorders (92). The isometric contractions recommended at the end of the ToePro exercise routines are especially important, as new research is consistently showing that holding isometric contractions while muscles are in their lengthened positions increases tendon resiliency more than conventional exercises (93,94). Strong and resilient tendons make us more efficient as we walk and run and protect us from getting injured as resilient tendons absorb force that would otherwise damage our muscles.

Last but not least, I highly recommend getting retested every few months as the rapid rate of improvement is really surprising. This is especially true for people who performed poorly on multiple tests. Seeing objective improvements is a great motivator, especially in people who dislike exercising. Although it seems like a big commitment, finding a way to consistently exercise 2 to 3 hours per week is a small price to pay considering the fact that in addition to reducing your potential for falling, regular exercise has been shown to protect against osteoarthritis, heart disease, stroke, diabetes, hypertension, cognitive declines and even cancer (95-100). The respected researcher Herman Pontzer spent his entire career studying the effects of exercise on a wide range of degenerative diseases and concluded that if you want to remain healthy and active as you get older, "exercise is not optional, it's essential" (101).

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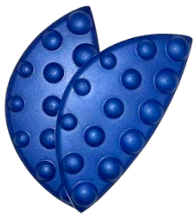

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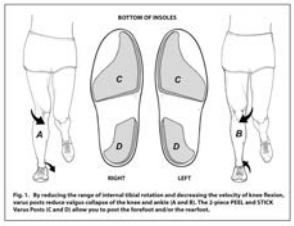

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