Why do female athletes hurt their knees so often - and how can they protect themselves from knee injuries?

Girls and women are much more at risk of serious knee injuries than their male counterparts. But research has shown that strength training has an astonishingly protective effect. Owen Anderson describes the curious vulnerability of the female knee and offers an exercise programme designed to keep it injury-free.

It's sad but true: female athletes who take part in sports involving jumping and 'cutting' (soccer, basketball, volleyball, gymnastics etc) have a risk of knee injury that is 4-6 times higher than for men taking part in the same sports. (1).

In the United States, the knee injury rate among female collegiate athletes runs at a stunning one per 1,000 'athlete-exposures' (an 'athlete-exposure' is simply a workout or competition). With over 100,000 college women taking part in organised sports each year, there are more than 10,000 knee injuries per year - or more than 1,000 per month (given a nine-month school year). To put it another way, if just 50 teams with 20 female athletes each carry out their workouts on a particular day, on average at least one serious knee injury would result (2).

Many of these injuries are devastating - from both a personal and financial standpoint. In the United States alone there are an estimated 2,200 complete ruptures of the knee's key internal supporting structure - the anterior cruciate ligament (ACL) - in female collegiate athletes each year, with the total cost of medical treatment running to millions of pounds. The average cost of care, including ACL reconstruction and rehabilitation, is about £11,000 per patient, which would add up to more than £24 million per year. In addition, a female athlete with an ACL rupture will usually miss an entire sporting season, may lose her athletic scholarship, and is likely to experience significant mental pain and stress(3). Bear in mind that these figures are probably just 'the tip of the iceberg', since they omit school athletes completely. In the US, as in the UK, there are many more participants at secondary school than at college, so the total number and cost of injuries in secondary schools are likely to be significantly greater. In the United States, there are probably about 20,000 serious knee injuries among female high school athletes per year, ratcheting the total cost of care for all female athletes - for knee problems alone - to about £70 million. Injury rates in the UK are likely to be similar, which would imply a total of more than 6,000 serious knee injuries per year, at a cost of £14 million. Secondary school girls have knee surgery five times more often than boys, and knee surgeries make up 70 percent of all athletic-related surgeries for young women(4).

The key strap of tissue

Why do anterior cruciate ligament (ACL) ruptures occur, and why do they happen more frequently in girls and women? To understand ACL ruptures and their preference for female athletes, you first need to know that the ACL is the key strap of connective tissue which stabilises the knee joint and connects the back of the femur (thigh bone) with the front of the tibia (shin bone). The word 'cruciate' in this key ligament's name means 'cross-shaped' or 'marked with a cross', a seemingly odd designation for a straight strap of connective tissue, which is roughly the size of one's little finger. However, within the knee joint, especially when the tibia is rotated in an internal direction (counterclockwise for the right knee, clockwise for the left knee), the anterior cruciate ligament (ACL) runs over the front of - and is roughly perpendicular to - another key supporting structure within the knee called the posterior cruciate ligament (PCL), creating a 'cross' of connective tissue

cords within the knee. An easy way to picture this is to cross your index finger under your middle finger; the middle finger represents the ACL and the index finger is the posterior cruciate.

The cruciates provide support for the knee and guide rotational movements at the knee joint. Basically, the ACL prevents hyperextension of the knee, limits excessive forward movement of the tibia during knee flexion, and controls internal rotation of the tibia. It's possible that the ACL also controls external rotation of the tibia, especially since it tends to be wrapped around the inside of the lateral femoral condyle (the bony projection at the outside bottom of your femur). The scenarios leading to injury are varied, but many experts believe that most ACL injuries occur not as a result of collisions but after landing from a jump or prolonged explosive stride(5). This is important because if most severe ACL injuries result from breakdowns in ACL tissue during normal sporting activity, dynamic strengthening of the ACL and its associated tissues should lower the risk of injury appreciably.

Although collisions are not as important as other mechanisms of knee and ACL injury, they can create mayhem. For example, someone might collide with you as you are running along, slamming into your leg near the knee while the foot of that leg is planted on the ground. The sudden movement of the tibia which would result could tear the ACL surprisingly easily (remembering that the ACL attaches to the top-front of the tibia). Alternatively, you might step on someone else's foot while running (or while landing after jumping during a basketball or volleyball game), causing your knee to hyperextend; sudden hyperextension at the knee can easily rip the ACL out of its moorings. Or you might simply attempt to come to a sudden stop, often while twisting your leg at the knee, to get out of the way of another athlete or to react quickly to the flight of a soccer ball. The extreme knee flexion and torquing which result can easily damage the ACL.

Incidentally, if you do serious harm to your ACL during activity, you'll often hear a 'pop' when the injury occurs, and swelling will follow almost immediately. In addition, the knee itself will tend to be quite unstable, usually 'giving way' during weight-bearing.

Wider female pelvis a factor?

Why are females at greater risk of ACL trouble? The reason is unclear, but some sports medicine experts believe it is primarily because of anatomical differences. For one thing, the intercondylar notch - a small chasm at the bottom of the femur through which the ACL passes - tends to be smaller in females than in males(6). Thus it is theoretically possible that during cutting and jumping movements, the narrow female notch may fray and weaken the ACL. Any fraying of the ACL would tend to be more serious in female athletes since the female ACL is usually a smaller structure.

In addition, the wider female pelvis tends to exaggerate the angle made at the knee between the femur and tibia when the foot is planted on the ground, increasing inward pressure on the knee and external rotation of the tibia, and thus placing excessive stress on the ACL(7).

Even more interesting is the theory that the ACL is more lax in females than males - and thus presumably more susceptible to overstretching(8). There are receptors for both oestrogen and progesterone on the ACL and the theory suggests that increases in one or both of these hormones may slacken the ACL, heightening the risk of damage. It is known that a woman's ligaments tend to loosen up as a result of the hormonal changes associated with pregnancy, so this theory is not too far-fetched and, if true, would also suggest that the risk of injury would vary with the menstrual cycle(9).

Studies from the University of Michigan have shown that female athletes have less strength in their leg muscles and slower muscle-reaction times than males, which would increase the risk of ACL trauma. The reaction-time disparity is particularly interesting: it is clear that to optimise the chance of keeping your ACL intact, you need both to boost the strength of your hamstrings (to help keep the tibia in place during landings from jumps and sudden stops) and to increase the speed with which your hamstrings react to ACL-stressing movements. If they're slow to react, they may be unable to protect the ACL in time to avoid injury, however strong they are.

Following this research, scientists at the Cincinnati Sportsmedicine Research and Education Foundation and Deaconess Hospital in Ohio detected a significant imbalance between hamstring and quadriceps muscle strength in female athletes before training. Importantly, male athletes had 'knee-flexor moments' (an indicator of hamstring strength) during landing from a jump which were three times higher than for females(10).

The Cincinnati researchers went on to design a plyometric, stretching, and strength-training programme for female athletes which decreased peak landing forces at the knee by minimising unnecessary side-to-side movements of the knee during landing(10). They showed that the plyometric -strengthening programme increased hamstring muscle strength and power, elevated the hamstring/ quadriceps peak power ratio and fortified hamstring strength during lateral and medial movements of the knee (in addition to better balancing strength in those opposing directions).

Curious about whether these wonderful advances in knee strength would actually lower the risk of knee injury, the researchers carried out a prospective follow-up study in which knee injury rates in athletes using the strength programme were compared with those of a control group(11). The study involved 43 soccer, volleyball, and basketball teams from 12 different secondary schools - a total of 1,263 participants: 15 all-female teams utilised the special strengthening programme for six weeks prior to the beginning of the competitive season and their injury rates were compared with those of 15 all-female teams and 13 boys' teams who did not use the programme.

Special strength training programme

During the competitive seasons, a serious knee injury was defined as a knee-ligament sprain or rupture causing an athlete to seek care from an athletic trainer and leading to at least five consecutive days lost from practice and games. All actual ACL ruptures were confirmed by arthroscopy.

The strength-training programme was fairly straightforward: there was an initial, two-week 'technique phase' of training, during which proper jumping technique was demonstrated and practised. There followed a 'fundamental phase', which focused on building a 'base' of strength, power, and agility. A third two-week 'performance phase' concentrated on achieving maximal vertical jumping height. Throughout the phases, the time spent on each exercise tended to increase. Each training session lasted 60-90 minutes, carried out three times a week on non-consecutive days. Stretching was performed before and after training.

During the technique phase, the following exercises were used:

1. 20-25 seconds of ankle bounces (bouncing up and down off the toes with knees slightly bent and arms raised);
2. 20-25 seconds of tuck jumps on mats (jumping from standing position and bringing both knees up to chest as high as possible);
3. 5-10 reps of broad jumps with 'stick' landings (jumping horizontally off two feet as far as possible and

holding landing point for five seconds);
4. 10-15 seconds of squat jumps on mats (jumping while raising both arms overhead, then landing in squatting position and touching both hands to the floor);
5. 2 x 30 seconds of double-legged cone jumps on mats (with feet together, jumping quickly back and forth over cones, from front to back and side to side);
6. 20-25 seconds of 180-degree jumps (jumping off two feet, rotating 180 degrees in the air, holding landing for two seconds, and then jumping again while reversing direction of body turn);
7. 20-25 seconds of bounding on the spot (jumping from one leg to the other straight up and down, progressively increasing the height and speed of movement).

The fundamental-phase workouts were as follows:

1. 30 seconds of ankle bounces;
2. 30 seconds of tuck jumps on mats;
3. 5-8 reps of jump, jump, jump, vertical jump (three broad jumps with a vertical jump immediately following the third);
4. 20 seconds of squat jumps on mats;
5. 1-2 runs of bounding for distance (bounding on the spot while gradually increasing height of each step);
6. 2 x 30 seconds of double-legged cone jumps on mats;
7. 30 seconds of scissors jumps (jumping up and alternating foot positions in mid-air after starting from stride position with one foot well in front of the other);
8. 5 reps per leg of hop, hop, stick landing (single-leg hops in which body position is held in place for five seconds after second hop, with distance of each hop increasing over time).

Finally, the performance-phase sessions, also carried out three times per week, included the following exercises: 1. 30 seconds of ankle bounces;

2. 5-10 reps of step, jump up, down, vertical (two-footed jump onto a 6-8-inch step, then a jump off the step , landing on two feet, followed by a maximal vertical leap);
3. 2 x 30 seconds of mattress jumps (two-footed jumps on a mattress or trampoline, performed first side to side and then back to front);
4. 5 reps of single-leg jumps for distance on mats (a hop of maximum distance on one leg, holding landing position with knees bent for five seconds);
5. 25 seconds of squat jumps on mats;
6. 3-4 runs of jump into bounding on mats (two-footed broad jump with landing on a single leg, followed by bounding for distance);
7. 5 reps per leg of hop, hop stick landing.

All three workouts included a 30-second rest period between exercises. A 15-minute rest at the end was followed by a weight-training workout involving abdominal curls, back hyperextensions, leg presses, calf raises, pullovers, bench presses, latissimus dorsi pulldowns, and forearm curls.

Strength training reaps benefits

This relatively simple six-week regime turned out to have a huge impact on the risk of serious knee injury. Untrained females experienced one serious knee per 2,325 'exposures' (workouts or competitions), while female athletes who used the programme described above were seriously injured only once per 8,333

exposures. Essentially, the untrained females experienced an injury rate which was 3.6 times higher than that of the trained group. And best of all, the injury rate in the trained females was not significantly higher than in the male controls!

Amazingly (and in contrast to the males) the strength-trained females did not experience a single serious non-contact knee injury during the school year. In other words, strength-trained females suffered series knee injury only on account of collisions, not because of intrinsic failure of the muscles around the knee and ACL. Overall, 10 of the 463 untrained female athletes sustained serious knee injuries, eight of which were non-contact. Just two of the 366 strength-trained female athletes experienced knee problems, with both injuries resulting from contact. Likewise, two of the 434 males had knee breakdowns (one contact and one non-contact).

Another astonishing finding was that not a single strength-trained female soccer player suffered a serious knee injury during the season, compared with five in the untrained group with terrible injuries and one boy who had an ACL rupture.

In summary, the strength-training programme worked big-time to prevent serious knee injuries in female athletes. It even eliminated the gender difference in the incidence of such injuries.

Why was this training so effective? The initial Cincinnati research suggested that it increased dynamic stability in the female athletes' knee joints, thus making it harder to put undue pressures on their ACLs. It also demonstrated that the training effectively decreased peak landing forces placed on the legs and knees following a jump, reducing the chance of an abrupt rupture of the ACL. In particular, the training enhanced hamstring strength relative to the strength of the quadriceps muscles. Bear in mind that the quadriceps pull the tibia in an anterior direction and thus produce greater strain on the ACL, while the hamstrings restrain anterior movement and thus protect the ACL. There is evidence that female athletes tend to be 'quadriceps dominant', which creates greater problems for the ACL; the strength training described above reduces this dominance by refurbishing the hamstrings and thus diminishing the pressure on the ACL.

Although the exercises used by the Cincinnati researchers were very good, the exercises described below should add even more strength to the muscles around the knee, particularly the hamstrings. They can be added to the Cincinnati workouts, providing even more foolproof protection for female athletes' knees.

Exercise 1:

The Six-Way Lunge with Arm Drop

This exercise stretches and strengthens the hamstring muscles on the back of the thigh in all three planes of motion (sagittal, frontal, and transverse). Strong and flexible hamstring muscles assist the ACL in its task of controlling the knee joint and preventing the tibia from moving excessively during knee flexion. * Begin by standing with feet parallel and hip-width apart, arms bent at the elbows so that your hands are directly in front of your shoulders;

* Take a long step forward with your right foot, as for a lunge, leaning your upper body forward by approximately 45 degrees at the waist. As your right foot makes contact with the ground, drop your hands on either side of your right knee;

* Quickly extend your right knee (ie straighten your right leg) and return to your starting position. Repeat with the left leg;

* From the starting position, step directly to your right with your right foot in a lateral-lunge position, upper body facing right and leaning forward over your right leg at approximately 45 degrees. As your right foot makes

contact with the ground, drop your hands on either side of your right knee, as above, with left foot pointing forward;
* Quickly extend your right knee and return your body to the starting position. Repeat the same motion with your left leg moving to the left;
* From the starting position, twist your body around at the hips and step diagonally and to the rear with your right foot in a backward-lateral-lunge position, upper body facing to the right-rear (at about 'four o'clock' position) and inclined over your right leg at approximately 45 degrees. As your right foot makes contact, drop your hands, as above, with left foot pointing forward;
* Quickly extend your right knee and return your body to the starting position. Then, repeat the overall motion with your left leg, moving it to the left-rear ('eight o'clock') position;
* Repeat the entire sequence described above three times for a total of 18 repetitions of stepping. Repeat twice more, with 30-60 seconds rest between each set of 18 reps.
Progressively toughen the exercise over a period of 4-6 weeks by increasing the resistance held in your hands (small dumbbells weighing up to 10 pounds) and the speed of the exercise.

Exercise 2:
The One-Leg Squat with Lateral Hop
Sudden changes in direction while running and jumping can cause injury to the ACL by placing increased stress on the knee. Lateral hopping movements help prepare the ACL and muscles around the knee for these sudden (and often unpredictable) movements in the frontal (side-to-side) plane. Even if you're not very worried about your ACLs, this is a great exercise! * Stand with your left foot forward and right foot back, feet about one shin-length apart from front to back and hip-width apart from side to side;
* Place the toes of your right foot on a step or block 6-8 inches high, with most of your body weight directed through the heel of your left foot. Bend your left leg and lower your body until there is an angle of about 90 degrees between the thigh and lower leg;
* Then hop upwards and laterally, so that your left foot lands about 6-8 inches to the left;
* On landing, immediately go into another squat, then hop back to your take-off point;
* Now repeat with the same leg but hopping to the right. Maintain upright posture throughout and keep your hands at your sides;
* Complete a total of 12 lateral hops (to the left and right) with your left leg before repeating with your right leg. Perform a total of three sets with each leg, with 30-60 seconds of rest between sets.
Be sure to perform this exercise only on a resilient service with some 'give', eg an aerobics floor, a wooden gym floor, a grassy surface, soft dirt or a rubberised track. Hopping repeatedly on concrete or asphalt may increase the risk of overuse injuries to the lower leg.

Exercise 3: Zig-Zag Runs
This exercise helps develop the balance and body control required to move in multiple directions at various speeds. The runs force the knee joints to move through a number of different angles and directions, thus mimicking movements which can lead to ACL injury in unprepared athletes.

* Start by running straight ahead at half speed for about five metres;
* At the 5m mark, cut quickly to your left for several strides by pushing off your right foot and moving in a left-forward (diagonal) direction;
* Then cut back to the right for several strides by pushing off your left foot and moving in a right-forward (diagonal) direction;
* Repeat this sequence for a total of 8-10 cuts (4-5 to the right and 4-5 to the left);

* Perform 3-5 sets of this exercise, with a break of 30-45 seconds between each run.
Gradually increase the intensity of your zig-zag runs over 4-6 weeks by running faster and also by changing the number of strides between direction changes (vary the number of strides between one and five). If you participate in sports which involve running backwards (eg football, rugby, and basketball), complete some of the sets in a backward direction.

Exercise 4: The High-Bench Step-Up
This old 'stand-by' for runners is great for warding off ACL problems.
* Stand on a bench about knee-high, with your body weight on your left foot and shifted towards the heel, right foot free and held slightly behind the body;
* Lower your body in a controlled way until the heel of the right foot touches the ground, but still supporting all your weight on your left foot;
* Return to the starting position by driving down with the left heel and straightening your left leg; * Repeat 10-12 times, then switch over to the right leg, maintaining upright body posture with your trunk at all times, with hands at your sides (with or without dumbbells).

Make this exercise progressively more difficult over time by increasing the resistance (with dumbbells up to 20lb) and raising the height of the step (up to mid-thigh height). The higher the step the greater the involvement of the hamstring muscles on the back of the thigh, which work in tandem with the ACL to stabilise the knee joint. Strong yet flexible and coordinated hamstrings help minimise the risk of ACL injury.

Over time, you should aim to increase the speed with which you carry out all of the above exercises, thus making your hamstrings specifically strong at the rates of movement which are most likely to produce injury. These exercises should help keep your knees sound and your ACLs intact. They are likely to be particularly useful as part of regular strength training if you play basketball, soccer, volleyball or any other sports which involve jumping or cutting.