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*Note: The contents page is partially visible, but the complete list of chapters and authors is provided.*
You only have to turn on the TV or open a newspaper to realize that sports injuries in youth sports are a hot button issue. And of all the sports injuries that make the news, concussions and ACL tears get the most attention.

These injuries were the focus of the presentations at the First Micheli Lecture September 29, 2013. We were pleased that so many experts in their fields accepted our invitation to speak on topics related to these and other issues in sports medicine for the young athlete, and that the result was a full-capacity audience of healthcare professionals who wanted to spend their Sunday listening to the presenters’ excellent talks.

We are especially grateful to Dr. Lars Engerbretsen, world-renowned in his field, who accepted our invitation to be the keynote speaker at the First Micheli Lecture.

We thank all our presenters for providing us with summaries of their talks so that we could prepare these Proceedings of this event.

As always, it’s important we acknowledge our debt to Dr. Lyle Micheli. His vision and pioneering work in the field of pediatric sports medicine laid the foundation for everything that led up to today’s events, not least of all the founding of the Division of Sports Medicine here at Children’s Hospital and the recent opening of the Micheli Center for Injury Prevention.

With all the focus on sports injuries, it’s sometimes easy to forget the many benefits that sports offer our young people. It’s because we believe so strongly in these benefits that most sports medicine doctors devote their lives to this field. It’s not just physical benefits that accrue from sports participation – it’s psychosocial benefits as well. As the father of three daughters, I am especially struck by the studies showing the psychosocial benefits of sports participation on young women.
And so while we believe strongly in developing the most effective ways to treat and manage sports injuries, including concussions and ACL tears, it’s because we don’t want to deny our kids the benefits of sports participation that our ultimate goal is to find ways to prevent injuries. For that reason it was prevention that was the focus of the First Micheli Lecture, and it is prevention that will be a recurring theme in the presentations in these Proceedings.

These Proceedings contain summaries of the excellent presentations made by the participants. Our speakers made sure their talks would be helpful to as broad a range of readers as possible. We believe the texts accurately reflect the depth and breadth of information that was imparted to the attendees and we trust that this document will be a helpful resource and a valuable contribution to the literature.

*Dr. Kocher is a Professor of Orthopaedic Surgery at Harvard Medical School and the Associate Director of the Division of Sports Medicine, Boston Children’s Hospital*

There are many people who worked long and hard to make the First Micheli Lecture a resounding success. The following persons deserve special thanks:

Kassandra Casiano  
Brooke Christian  
Dave Chrisom  
Brian FitzGerald  
Joe Founds  
Lisa Fratt  
Stacey Gigante  
Bethel Haile  
Adam Knee  
Ginelle MacDonald  
Jill Muise  
Lesley Niccolini  
Maureen Piccolo  
Erin Tornatore  
Mandy Wong  
Karen Wright  
Diana Zapata
The following text was adapted from the oral presentation made by Dr. Stein at the First Annual Micheli Lecture.

The purpose of this presentation is to give some background on what we’re going to be discussing today.

Let’s start by addressing some of the benefits of physical activity. There are many of them—including physical, psychological/emotional, academic, and social—and these are some of the reasons we want to keep as many children as possible participating in sports.
Explosion in Youth and Children’s Sports

The last 30-40 years has seen an explosion in the participation of children and youth in sports. The passage of Title IX legislation in 1972 prohibiting discrimination on the basis of sex opened the floodgates for the participation of girls in sports. This didn’t just benefit girls – but sports in general.

We have seen a ten-fold increase in high school sports participation and a five-fold increase in college sports participation. There are currently 35 million children and youth participating in sports. About 70% of all the kids aged 6-18 in this country participate in organized sports.

Figure 1.1 from the Women’s Sports Foundation shows that about 69% of girls between grades 3 and 12 are engaged in

MULTIPLE BENEFITS OF PHYSICAL ACTIVITY & SPORTS PARTICIPATION

*Physical:* Decrease obesity, heart disease, stroke, osteoporosis, diabetes

*Psychological/emotional:* Decrease depression, increase self esteem

*Academic:* Increase graduation rates

*Social:* Develop teamwork, perseverance, discipline
organized sports, compared to 75% of boys. Although the number of girls participating in organized sports has increased, there is still room for improvement.

There are other disparities in sports participation—inequalities in ethnicity, socioeconomic status, and urban versus rural inequalities. These disparities should be kept in mind throughout the day’s proceedings; if we want to advance the health of the entire population, we need to better understand why these disparities exist and find ways to correct them.

**Kids’ Sports Have Changed**

Not only have we seen a tremendous increase in the total number of children and youth participating in organized sports, but we have seen a fundamental change in the way kids play sports. With the growth of organized sports we see a much higher level of competition, especially early on, with kids starting at 4 and 6 years old. We now see kids playing specific sports year-round instead of having different sports seasons or taking a season off. We now know that this predisposes kids to certain types of injury.

There are also risks inherent to the young body, such as damage to the growth cartilage and nutritional concerns. There are also variations in physical and emotional development which come into play when kids of the same age but different levels of development play against each other.
The Cost of Injury

Every day 7,100 kids are seen in emergency rooms around the country. That translates into 227 million emergency room visits every year. Eleven billion dollars is the cost of providing that emergency care. Obviously this is just the tip of the iceberg; it does not include all the care provided by school nurses, team trainers, primary care doctors, or sports medicine specialists. It doesn’t include hospitalizations, surgeries, braces, and medications. It does not include indirect costs – parents taking kids to their appointments and missing work, for example. It also does not include those kids who do not get full care, who because of injury may just drop out of sports.

If we look specifically at high school athletes there are approximately 2 million injuries per year. That translates to half a million doctor visits and about 30,000 hospitalizations. We also know that sports and over-exertion are the number one cause of injury-related visits to the primary care doctor.

We’ve looked at the “bad” numbers. Here’s a good one – 50, as in 50 percent. The CDC estimates that 50 percent of sports injuries are preventable. And I think that’s why we’re all here early on a Sunday morning - because we know there is so much we can do to prevent many of these injuries.

Obviously we will never be able to prevent all injuries – there are inherent risks in playing sports. But there are so many things we can do to reduce the chance of injury. And that’s what we are here to learn about today.
Overuse vs Acute Injuries

When we talk about prevention, we often talk about overuse injuries and acute injuries.

Overuse injuries are by definition repetitive microtrauma that occurs over time. Because these injuries build up over time – conditions such as stress fractures, tendinitis, etc. - there are multiple opportunities for us to intervene, whether it’s to stop the injury from ever occurring or to stop it from progressing. We’ll hear about this later in our breakout sessions on dance injuries, throwing injuries, running injuries, etc. as all of these activities have significant overuse injury risks.

We also need to be concerned about preventing sudden traumatic injuries - things like concussions and ACL injuries. With concussions, it may be about changing the rules of the games. With ACL, we may need to address how kids stabilize their knees and to address vulnerabilities before they result in a young athlete getting injured.

Preventing Injuries

One of the great things about prevention is that there are so many levels of it. That’s why the Micheli Center and other programs have so much to offer. We want to work with the athlete, no matter what point they’re at.

Ideally, we would like to completely prevent the injury. We would like to evaluate the athlete to see if there are any vulnerabilities, imbalances, or weaknesses, so we can address those in such a way that the injury will never occur.

Unfortunately we can’t always do that. We may be faced with an athlete who has already had an injury. We see that as a
window of opportunity. We want to look at what risk factors are present that might have led to that injury and to see what we can change to make sure the athlete doesn’t get reinjured. In some cases we are just trying to manage the injury so it doesn’t get worse. If someone has a stress reaction, we don’t want to it develop into a stress fracture. If someone has a concussion with symptoms, we don’t want to let them back onto the field where they might be at risk for another impact and a worsened injury. Ultimately we’re also trying to prevent chronic diseases. If we can prevent an ACL tear, then we are also going to prevent the likely onset of osteoarthritis. And if we’re keeping young athletes active and healthy, then they have a better chance of becoming active, healthy adults with lower risk of conditions associated with overweight and lack of physical activity. We know that exercise helps prevent a host of conditions from heart disease to stroke to osteoporosis to diabetes.

**A Model for Change**

I have adapted the Richmond model, created by former Surgeon General Julius Richmond. Dr. Richmond created the model to describe how to bring about public health change (*Figure 1.2*). He said you needed scientific knowledge, social strategy, and political will. The same model can be used to describe necessary factors in sports medicine injury prevention:

- **Scientific knowledge** – We need to understand what these injuries are. We need to collect data. We need surveillance programs. We need to be able to recognize patterns so that we understand these injuries better and we can figure out ways to prevent or treat them.
• **Social strategy** – We need interventions that can be tested to prevent injuries from occurring. We need individual strategies, working with athletes to identify their unique, individual needs. We also need population-based strategies – we need to look at whole teams, whole areas, or whole sports, to figure out how we can reduce the risk for everyone.

• **Political will** – We need the motivation, the funding, and the resources to put these changes into effect.

In summary, the burden of sports injuries in young athletes is way too high. Prevention is absolutely necessary – and absolutely possible. There are measures we can all take to help put prevention into practice, and the attendance at this event is evidence that there is real interest in taking action. The ultimate goal of sports injury prevention is to keep people active and healthy for a lifetime.

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*A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at:*

Suggested Readings


Hambidge

AJ Davidson, R Gonzales, & JF Steiner.
The focus of today’s proceedings is sports injury prevention. There is sometimes a tendency to think sports injury prevention is a modern phenomenon, but in fact there is a rich history of prevention in sports medicine. Some of it dates back thousands of years. And as we will see, the team physician has been in the forefront of these initiatives.
We can trace sports injury prevention back to the ancient Greeks. Dr. Herodicus began his career in the fifth century BC as a coach in the annual Greek Olympics. He eventually became a physician and a team physician, and is believed to have tutored Hippocrates. Herodicus posited that the best form of preventive medicine was a combination of exercise and proper diet. Sometimes known as the “father of academic sports medicine,” Herodicus’s philosophies are what inspired the formation of the Herodicus Society of academic sports medicine physicians, three of whom are present today.

In Herodicus’s times there was a hospital near Athens that contained a sports gymnasium in addition to an amphitheater, clinic, and surgery, because it was believed during these times that exercise was a vital component of preventive medicine.
During the Renaissance there was a revival in interest in the ancient Greeks and Romans, and some of the sports medicine philosophies that emerged from this period were very progressive. For example, in the volume entitled “De Arte Gymnastica” published in 1573 in Padua, Italy, author Girolamo Mercuriale wrote that “Medicine has two parts – curative and preservative.” Preservative medicine, Mercuriale wrote, is divided into three parts:

- prophylactic: averts future disease
- preventive: defends existing health
- restorative: those who are ill are restored

These are ideas that do not sound at all out of place in 2013.

As we enter the modern era we see a sharper focus on caring for the athlete. This was a response to the rise of organized sports in the nineteenth century, and the restoration of the Olympic Games in 1896.

The first international sports medicine association was formed at the 1920 Winter Olympics in St Moritz, Switzerland. Called the Association International Medico-Sportive (AIMS), this organization eventually became the organization we now know today as Fédération Internationale Medico-Sportive, or FIMS. Initially its role was to provide the medical support needed by the IOC.
Eventually the IOC Medical Committee was formed. Quickly it became heavily burdened by monitoring drug testing. When the World Anti-Doping Agency (WADA) was formed in 2005 this took much of the burden off the IOC Medical Committee which, under the leadership of today’s keynote speaker Dr. Lars Engerbretsen, was then able to devote its energies to injury prevention. The IOC Medical Committee has hosted several important injury prevention summits that I have been privileged to attend. One of the most significant initiatives launched by the IOC Medical Committee is the one focusing on “lifetime injury prevention” through athlete profiling.

What about the history of sports injury prevention in the United States?

In the US, physicians began caring for university athletes in the late 1800s. Dr. William Conant formed the Medical Department of the Harvard Athletic Association in 1890. Harvard hosted many tournaments and athletic contests at the time—from rowing to running—and it wasn’t long before
these events started generating academic papers. One of the first of these was by Dr. Eugene Darling titled, “The effects of training: a study of the Harvard University crews,” which appeared in the *Boston Medical and Surgery Journal* in 1899.

Another milestone in sports medicine literature was a paper in the *Boston Medical and Surgery Journal* by Drs. Nichols and Richardson titled, “Football injuries of the Harvard squad for three years under the revised rules.” Published in 1909, the significance of this paper was that it examined the outcome of rule changes enacted to reduce the incidence of injury.

The first major book on sports medicine in the United States was published in 1936. “Athletic Injuries – Prevention, Diagnosis and Treatment” was authored by Dr. Augustus Thorndike. Note that the book has the word “prevention” is listed first in its subtitle, and indeed, Dr. Thorndike focused on prevention in this and subsequent editions of the book, with chapter one devoted to this very topic. Very forward thinking, Dr. Thondike wrote about the importance of training, diet, mandatory protective equipment and presided over the introduction of trainers onto Harvard athletic teams in 1925. I believe it was Dr. Thorndike’s role as a team physician that inspired this focus on prevention.

The Sports Medicine Clinic at Boston Children’s Hospital was the first clinic of its kind focused on young athletes in the U.S. We founded it in 1974. Our articles of incorporation in 1978 read in part that our goal was to “diagnose, treat, and prevent sports injuries in children.”
Our early papers looked at prevention and this area has always been an interest of mine. Some of our early work tried to establish mechanisms of preventing injuries through the identification of risk factors. We initially divided them between “host” and “environmental” factors. Dr. Emery has done wonderful work in expanding upon these concepts and you’ll see that he has divided risk factors into four groups –

- Extrinsic risk factors – non-modifiable
- Extrinsic risk factors – potentially modifiable
- Intrinsic risk factors - non-modifiable
- Intrinsic risk factors - potentially modifiable

Of course, we want to address those risk factors identified as “potentially modifiable.” We want to address these potentially modifiable risk factors and either eliminate them or reduce their impact so as to lessen the incidence of injury.

My interest in sports medicine and rugby intersected when I published a paper in 1974 on the comparative incidence of injuries in rugby and football. My paper found that injuries in rugby were much lower than those in football, and were more comparable to injury rates seen in soccer. I established that most injuries occurred during games, not practice, which gave us an insight into how to prevent injuries.

In 1998 I organized the International Conference on Rugby Injuries and I think it is significant that the title of the Proceedings of that event was “Preventing Injuries in Rugby.”

What we have found is that it is possible to reduce the incidence of injuries in rugby if a comprehensive approach
is taken which includes possible rule changes and stricter enforcement of rules of the game involving safety.

We are now seeing rule changes made in football as a way of improving safety in this sport.

Back to the team physician. This individual is responsible for fieldside medical coverage along with a support staff that might include athletic trainers and other health professionals. The American College of Sports Medicine has a Team Physician Course—not a “sports medicine” course, mind you—which you can take in two parts. After completing this course you can serve as a team physician and play a very important role in injury prevention.

At the Division of Sports Medicine at Children’s Hospital we now require the physicians in our fellowship program to provide coverage for a local team. And so they are working all over the city in their capacity as team physicians involved in important preventive measures like pre-participation examinations. We are especially proud of our work providing coverage in underserved communities.

Injuries are not just “part of the game.” There are many measures we can take to reduce injuries in sports by focusing on addressing risk factors. Many of these were outlined in the position statement released by FIMS and the World Health organization in 1997 to which I was a participant and signatory.

Who would disagree that in children’s and youth sports, medical care should be focused on prevention?

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79297590
Suggested Readings

Applebloom, T, C Rouffin, & E Feirens.  
*Sport and medicine in ancient Greece.*  

Girolamo Mercuriale.  
*De Arte Gymnastica.*  
Padua, 1573

Darling, Eugene A.  
*The effects of Training: a study of the Harvard University crews.*  

Nichols, EH, & FL Richardson.  
*Football Injuries of the Harvard Squad for three years under the revised rules.*  

Thorndike, A.  
*Athletic Injuries: Prevention, Diagnosis and Treatment*  
1936, 1942, 1948

O’Neill, DB, & LJ Micheli.  
*Recognizing and preventing overuse injuries in young athletes.*  

Micheli, LJ, & RJ Riseborough.  
*The incidence of injuries in rugby football.*  
American Journal of Sports Medicine 1974;2;93-98

Micheli, LJ, & MD Jenkins.  
*Preventing rugby injuries. Proceedings of the International Conference on Rugby Injuries, Boston, MA*  
May 29-31, 1988; US Rugby Football Foundation

Collins, CL, LJ Micheli, EE Yard, & RD Comstock.  
*Injuries sustained by high school rugby players in the United States, 2005-2006.*  

FIMS/WHO Ad Hoc Committee on Sports and Children – Micheli, LJ (Chair), N Armstrong, O Bar-Or, C Boreham, K Chan, R Eston, AP Hills, N Maffulli, RM Malina, NVK Nair, A Nevill, T Rowland, C Sharp, WD Stanish, & S Tanner.  
*Sports and children: consensus statement on organized sports for children.*  
Dr. Micheli has achieved so much in his career that it would have been easy for him to rest on his laurels. Instead, he spearheaded an initiative to change the way we look at sports medicine at Children’s Hospital.
At a full meeting of our faculty and staff in 2010, Dr. Micheli informed us that the same way the Sports Medicine Division had found new and better ways over the last 30 years to diagnose and treat sports injuries, we were now going to find new and better ways to prevent those injuries.

And so from Dr. Micheli’s challenge arose the idea to create a facility for research and implementation of sports injury prevention strategies.

As the idea gathered momentum and we fundraised the $2 million to build it, equip it, and staff it, we all knew there could only be one person’s name on the front of the building and that would be Dr. Micheli’s.

Goals of the Center

The role of the Micheli Center for Sports Injury Prevention is two-fold. First, it has become one of the few centers conducting sports injury prevention research. Second, we believe we are the only center in the world that offers a direct service to athletes, a place where athletes can come, learn which injuries they are at highest risk of sustaining, find out what steps they can take to reduce their risk of those injuries.
The blueprint for what it is we do at the Micheli Center was to be based on a Protocols Manual Dr. Micheli charged our faculty with developing. That massive resource was to address all the injuries we see here at the Sports Medicine Division and all the sports we cover. The Protocols Manual was to include all the medical literature, all of the scientific literature about each injury and each sport. We completed the manual and put together a huge resource of several hundred pages.

To make the Protocols Manual a practical resource, we hired a full time computer programmer, Felix Wang, who developed our customized software, SIPRx. In addition, we hired athletic trainer Emily Hanson to take the data in the manual, supplement it with newer research, and enter the criteria into the software program so that it can identify any measurement that is a risk factor for a certain sports injury, put that injury on a given athlete’s list of high risk injuries, and generate a prescription of steps the athlete can take to reduce the risk of sustaining that injury.

How We Do It

So how does this work? If you’re an athlete and you come to the center, you first sit down at a computer and give us some basic information – how old you are, what sports you play, what sport injuries have you sustained in the past, how many hours a week you train, how many hours a night you sleep, a little information about your diet, and other variables that are associated with injury.

Then you move out to the floor and when you’re on the floor our injury prevention specialists measure over 300 variables that are associated with sports injuries. These include your
bony angles, range of motion in your joints, strength in opposing muscles groups, flexibility, speed, agility, power – everything that according to the literature is associated with a sports injury. You then meet with an MD who has in front of them the list of injuries you’re at highest risk for and the measures you can take to reduce your risk of injury. The doctor performs a physical examination dedicated to the parts of the body that you’re at highest risk of injuring and goes through the prescription. The process I’ve just described takes 3 to 3.5 hours, depending on how many sports you participate in. When you leave, you receive a fairly substantial packet that lists the injuries you’re at highest risk for and the steps you can take to reduce your risk of injury. Some of the steps are quite easy – make this adjustment to your training regimen, or that adjustment to your sleep schedule, or consider using a certain type of equipment.

Some recommendations demand more from the athlete – you need to improve your strength in the following muscle group or improve your range of motion in the following area. The straightforward steps are easy to put into place. The more complicated need to be worked on, and athletes can come back to the center to work them. They can also take the program to a gym or YMCA near their home and work on

Vertical leaping ability is measured using a Vertec tester.
them there. Or they can take it to their strength and conditioning coach, personal trainer, or whomever else it is they work with, and do it with that person.

If they do their program outside our facility, we recommend that every three months they can come back and get re-assessed to see if they have improved on those measures – have they reduced their risk of certain injuries and where can they go from there?

We have partnered already with many of the area strength and conditioning groups, physical therapy groups, and with the local YMCA’s of New England.

When they’re out on the floor with our Injury Prevention Specialist (IPS), if they enter a number that is associated with the increased risk of an injury, the computer program, SIPRx, automatically pulls that injury onto their list. When you have an injury pulled on your list it also populates which steps you can take to reduce your risk of injury and change that risk factor.
Figures 3.1 - 3.6 show screenshots of our overall system which shows how we can track the athlete’s progress.

Figure 3.1
### Measurements History

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**Birthday:**

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**Figure 3.2**

**Figure 3.3**
# Measurement Report

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**Birthday:**

**Appointment Date:**

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<tr>
<td>Left Hip ER Seated ROM</td>
<td>23 Degrees</td>
</tr>
<tr>
<td>Left Shoulder IR @ 90 ROM</td>
<td>59 Degrees</td>
</tr>
<tr>
<td>Right Shoulder IR @ 90 ROM</td>
<td>39 Degrees</td>
</tr>
<tr>
<td>Total Left Shoulder Arch ROM</td>
<td>149,000 Degrees</td>
</tr>
<tr>
<td>Total Right Shoulder Arch ROM</td>
<td>154,000 Degrees</td>
</tr>
<tr>
<td>Left Elbow Ext ROM</td>
<td>2 Degrees</td>
</tr>
<tr>
<td>Right Elbow Ext ROM</td>
<td>1 Degrees</td>
</tr>
<tr>
<td>Right Ankle Dorsiflex ROM</td>
<td>-3 Degrees</td>
</tr>
<tr>
<td>Left Ankle Dorsiflex ROM</td>
<td>-6 Degrees</td>
</tr>
<tr>
<td>Right Popliteal Hamstring Angle</td>
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</tr>
<tr>
<td>Left Popliteal Hamstring Angle</td>
<td>62 Degrees</td>
</tr>
<tr>
<td>Right Shoulder Supraspinatus Strength Avg</td>
<td>120,000 Newtons</td>
</tr>
<tr>
<td>Right Shoulder ER Strength Avg</td>
<td>112,500 Newtons</td>
</tr>
<tr>
<td>Left Shoulder Supraspinatus Strength Avg</td>
<td>119,000 Newtons</td>
</tr>
<tr>
<td>Left Shoulder ER Strength Avg</td>
<td>129,500 Newtons</td>
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<tr>
<td>Hip Adduction Ratio L:R</td>
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<td>Hip Abduction Ratio L:R</td>
<td>371:370</td>
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<tr>
<td>Total FMS score</td>
<td>16,000 FMS Score</td>
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<td>Front Plank</td>
<td>116 Seconds</td>
</tr>
<tr>
<td>Left Stance Single Leg Bridge</td>
<td>91 Seconds</td>
</tr>
<tr>
<td>Right Stance Single Leg Bridge</td>
<td>90 Seconds</td>
</tr>
<tr>
<td>Abdominal Brace</td>
<td>43 Seconds</td>
</tr>
<tr>
<td>Right Foot Forward Tandem</td>
<td>44.06%</td>
</tr>
<tr>
<td>Vertical Jump Total Height</td>
<td>23,000 Inches</td>
</tr>
<tr>
<td>Pro-Agility</td>
<td>5.2 Seconds</td>
</tr>
</tbody>
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**Notes**

- Focus on core strength, especially lower abdominals and throwing from the core

---

**Figure 3.4**
Top Potential Injuries

Knee Collateral Ligament Sprain/Tear
Your knee has 4 main ligaments that stabilize the knee joint: Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), Medial Collateral Ligament (MCL) and the Lateral Collateral Ligament (LCL). The collateral ligaments help stabilize the knee during side to side motions. Most collateral ligament injuries happen from a contact with another player or during rapid cutting and pivoting.

Spondylolysis/Spondylolysis
The spine is made up of bones stacked on top of one another. A spondylolysis is a defect to a portion of the spine. This defect is typically on one side of the bone. When the defect occurs on two sides of a spine bone, the bone can slip out of place. The slippage is known as spondylolysis.

Lumbar Muscular Strain (Low Back Pain)
A strain occurs when the muscle fibers are abnormally stretched or torn and results in inflammation. Your lumbar spine (lower back) is active in almost every movement and activity, which makes the area prone to injury.

Medial Epicondylitis
A group of muscles of your forearm that bend your wrist forward attach on the inside of your elbow. These muscles and tendons can become inflamed with repetitive stress such as overhead throwing or a backhand swing.

Elbow Ulnar Collateral Ligament (UCL) Sprain/Tear
Bones are connected to each other by ligaments. In your elbow, there is a ligament called the "UCL." When this is torn or sprained elbow joint can become unstable. Injury to this area often occurs from repeated stress to the elbow.

Shoulder Impingement Syndrome
Overhead activity narrows the space between the shoulder bones and the shoulder muscles. When this occurs, the shoulder bone known as the acromion can pinch the tendon in your shoulder. Repetitive movement can cause pain, weakness, and decreased range of motion of the shoulder joint.

Little League Shoulder
This is pain in the upper arm or shoulder caused by repetitive upper arm movements such as throwing, hitting, swinging or swimming. It is caused by an irritation or inflammation of the growth plate of the upper arm, also called the humerus.
Other Services

There are also specific services for athletes who might want focus only on one or a few injuries or the injuries common in a specific sport or other form of athletics. A good example would be someone my age who doesn’t participate in team sports but does a lot of road races or cycling or triathlons who wants to come in because they’ve battled with plantar fasciitis over the years and had some illiotibial band issues, and they just want to reduce their risk of suffering those injuries again.
We have a dedicated running injury prevention program run by Pierre d’Hemecourt, head of primary care at the Sports Medicine Division, who is also one of the medical directors for the Boston Marathon. In this program athletes get up on a treadmill that has a force plate underneath and measures the impact forces of the foot as they run. There are video cameras from the side and from the rear that allow the specialist to see if they are heel strikers, mid-foot strikers, or fore-foot strikers. The specialist can also see if the runners over-pronates or drop their pelvis as they run. All these variables are associated with the risk of running injuries. If our specialists identify variables that need correcting, the runner can undergo gait retraining where they get advice and video feedback and work with a specialist on changing their gait to reduce their injury risk factors.

There is an ACL prevention class. Many athletes come in who’ve seen their sister, brother, or teammate tear their ACL. Or they themselves have torn their ACL and don’t want to tear it again—or tear the other one—and want to know what they can do to reduce their risk. The Division of Sports

Other Services

- Running Program
- Concussion Preparation and Prevention
- ACL Injury Prevention Class
- Coaching and Community Clinics
- Activity for Sedentary Kids
- Dance Program
- Training (Independent and 1 on 1)
- Scholarships for Underserved Athletes
Medicine has a lot of doctors who specialize in ACL management—Drs. Murray, Kramer, Kocher, Heyworth, and Micheli—who have used their experience and research to develop a program where athletes can work on changing their risk factors for ACL tears to decrease those risks.

We also have lectures and classes for the community as well as coaches and parents—and also for physicians who are not already involved in sports medicine.

Dr. Stracciolini runs what’s called the Active Kids program which does two things: 1) encourages exercise among all children and 2) works with kids who were previously sedentary so that when they do enter sports they have developed the neuromuscular control required to lower their risk of injury, using a program we developed with our collaborators at Cincinnati Children’s Hospital—including Dr. Greg Meyer whom you’ll hear from later. The Division of Sports Medicine has a lot of doctors who specialize in ACL management—Drs. Murray, Kramer, Kocher, Heyworth, and Micheli—who have used their experience and research to develop a program where athletes can work on changing their risk factors for ACL tears to decrease those risks.

For many years Dr. Micheli, Ruth Solomon, Mickey Casella, and Heather Southwick have treated and prevented dance injuries. They helped us develop our dance program. Dancers have a distinctive injury pattern and they can come into our center, get assessed, and undergo a dance-specific injury prevention evaluation. We have a force-absorbing dance floor, a mirror, and a ballet bar for these evaluations.

In addition, we also do private, semi-private, and small group training sessions for people who want to carry on their injury prevention prescriptions at the center.
The table below shows the number of athletes we have treated, effective as of September 29, 2013 (Fig. 3.7).

<table>
<thead>
<tr>
<th>Service</th>
<th>April</th>
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<th>June</th>
<th>July</th>
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<tr>
<td>ACL Services</td>
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<td>0</td>
<td>4</td>
<td>14</td>
<td>4</td>
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<td>35</td>
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<td>22</td>
<td>22</td>
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<td>26</td>
<td>20</td>
<td>33</td>
<td>121</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>45</td>
<td>118</td>
<td>123</td>
<td>253</td>
<td>571</td>
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</table>

**Figure 3.7**

**Insurance Coverage**

As you can imagine, at this moment insurance companies do not pay for this. Until it’s proven that we will prevent enough injuries that the cost of paying for prevention is less than the cost of the treatment they won’t cover it. Because we don’t want this to be a program only available to children of the affluent, we started a scholarship fund immediately after opening. We have $40,000 in donations so that we can help kids who wouldn’t ordinarily be able to afford our programs come in and get them for free. We also coordinate with schools in under-served neighborhoods to bring kids out here.
Research Projects Underway

Part of our mandate, of course, is to be a research center. We want to do immediate research – using existing databases to determine the risk factors for injury, prevalence of certain injuries, etc. *(Fig. 3.8).* There is not a lot of normative data, so if you want to know what the quadriceps/hamstring ratio of most 9 to 12 year old soccer players is, it doesn’t exist right now, and so initially just finding out what is the normative data is a good starting place for a lot of this. We will also want to conduct retrospective cohort and case-
Research Initiatives

**Immediate**
- Descriptive studies
- Normative values
- Retrospective case control studies

**Intermediate**
- Effect of prescriptions/compliance on measurements
- Immediate data studies (methods of equipment removal, effects of interventions on one time measurement outcomes, etc.)

**Long-term**
- Prospective cohort study of risk factors
- Effect of Rx on injury rates

control studies – assessing the biomechanical factors in injured athletes to see how these differ from those in uninjured athletes. This will help us identify new variables.

The **intermediate research** will involve following up with what they do with the prescription we give them at The Micheli Center. We will want to know how best to customize prescriptions to ensure compliance and effectiveness.

Finally, there is the **long-term research**, which I think is the most exciting area. We have applied through our institutional review board so that every three months we can email or text a handful of questions to these athletes for their feedback. We send them a copy of their prescription, they put a check in a box next to every component of their prescription that they have completed twice a week or more since their visit, so we know if they’ve done their exercises. Number two, we ask them if they’ve been injured playing sports in the last three months. If they’ve been injured we ask to contact them to get details about their injury, what was it, how did it occur, how
was it diagnosed, etc. And since we have those 317 variables on these athletes, we can understand which variables are associated with sports injuries.

**Future Directions**

One of the challenges we face is making people understand how important it is that we address injuries in sports. I know that those of you who are in this room are convinced of it, but outside this room there may be less of an understanding. So one strategy I use is to tell parents that a substantial proportion of life-threatening injuries in children—39% in fact—occur during youth sports, and that is a statistic that usually gets their attention. These injuries include direct trauma to the brain, intracranial hemorrhages, cervical spinal fractures, splenic ruptures, and aortic ruptures.

It’s also important to note that obesity is also a life-threatening condition, although not in the immediate time frame, and an injury that prevents a child from participating in sports increases the likelihood that child will become overweight or obese. And this is why addressing “exercise deficit disorder” is also going to be a priority at the Micheli Center.

All of us at the Micheli Center for Sports Injury Prevention are excited about what the future holds in store for this new facility, both in the areas of research of injury prevention and implementing specific injury prevention strategies.

*A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: [http://vimeopro.com/anchorline/micheli/video/79297586](http://vimeopro.com/anchorline/micheli/video/79297586)*
When I arrived at the Sports Medicine Division in 1996 Dr. Micheli had a very efficient operation in place. It’s been my pleasure since I arrived to share in and help the program. Our model here at the Division is to look at the athlete not just in terms of diagnosis and treatment but also prevention. If you look at the clinicians who have been involved in our practice, you will see that...
we have a nutritionist who works with all aspects of management, two excellent podiatrists, and a sports psychologist. The role of the sports psychologist has really expanded as we have seen an increase in the number of concussions, eating disorders, and athletes with repeated recurrent injuries.

Physical therapy has always been a focus of ours. We have five athletic trainers here at the Division and several new hires at the Micheli Center.

We have two nurses that help us with our ultrasound injections and at our Sports Concussion Clinic.

Of course, we have seven orthopedists who are expert in all forms of intervention, as well as 12 primary care physicians with multiple areas of interest. There are many different areas of interest among our medical doctors, including skating, dance, throwing, football, hockey, and running.

Members Of The Multi-Disciplinary Team

- Nutritionists
- Podiatrists
- Psychologist
- Physical therapists
- 5 Athletic Trainers
- 2 Nurses
- 7 Surgeons
- 12 Primary Care Sports Med Physicians

We have also developed areas of sub-specialization. We have a Sports Concussion Clinic, as Dr. Meehan just mentioned. Also a Dance Medicine Clinic dealing with the
professional dancers of the Boston Ballet as well as intermediate and novice dancers. We have an Injured Runner’s Clinic. Our Female Athlete Clinic is attended by sports medicine physician, an orthopedists, a nutritionist, and a sports psychologist who are all interested in the dynamics of injuries in the female athlete.

Our Ultrasound Clinic, which was launched in 2008, has become extremely useful. There is a lot of dynamic imaging that can be done for conditions such as hip impingement and different ligamentous and tendon abnormalities and instabilities around the elbow and wrist. One of the most exciting new areas of focus that we are going to be publishing on relates to hip impingement all the peri-articular impingements that can occur outside the hip. Also in the ultrasound clinic we are doing some novel things with PRP and other types of injections that are associated with regenerative medicine.

In the ultrasound clinic we are doing some novel things with PRP and other types of injections that are associated with regenerative medicine.

We have an active team of doctors looking at hip injuries and have young athletes coming in from around the country and the world to see us. Sometimes the problem is quite straightforward but at other times the problem is related to different bony abnormalities such as hip dysplasia that require careful evaluation.

**Specialty Clinics**
- Concussion
- Dance
- Injured Runners
- Female Athlete
- Ultrasound
- Hip
- *Brand new:*
  - Micheli Center
  - Biomechanics Clinics
The Micheli Center is the newest addition to our range of care. This is going to tie together many of the areas of care we provide, including the preparticipation evaluation, concussion assessment, female athlete screening, and of course, general fitness.

Since the Micheli Center opened in April, our multidisciplinary approach to sports medicine care of the young athlete has been greatly enhanced. For example, last week I was working with a young man who had a running injury. The presence of a biomechanics expert at the Micheli Center came in particularly useful as I was able to use his services to do video analysis of the athlete's foot-strike to help identify biomechanical problems that might be causing his knee pain. Once those problems were identified, I was able use other members of the team—podiatrists, for example, to create orthotics—to address the root cause of the problem.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79333583
It surprises many people to learn ACL injuries weren’t really a topic in pediatric sports medicine until quite recently. When I was training in the 1980s and later in the 1990s the common wisdom was that children didn’t get ACL injuries. Published in 1979, the landmark text by Dr. Jack Kennedy, The Injured Adolescent Knee, barely touched on the issue of ACL in young patients, and it was only when Dr. Micheli and I updated that text in 2006 did the topic receive coverage in that volume.
Of course, we now know that young people do indeed get ACL injuries and these are especially common in young athletes.

There is a lot of controversy today about how we should manage ACL injuries in younger patients – especially concerning initial treatment. There are also questions about whether treatment should be operative or non-operative and what technique to use due to the presence of growth plates.

One option after an ACL tear is the non-operative route. So if the athlete is still growing and he or she tears their ACL, they can be treated with rehab and bracing and kept out of sports until it’s time to reconstruct the ACL when they are skeletally mature. Some of the best work done in the area of non-operative treatment of ACL injuries patients has been by Håvard Moksnes, a student of our keynote speaker Lars Engebretsen. What they and other researchers have found is that the results of this approach have been quite poor; there have been high rates of knee instability, meniscal tears, and wearing of the articular cartilage which are all of concern to the long-term health of the knee.

### NONOPERATIVE RX (COMPLETE TEARS)

*Moksnes, Engebretsen, Risberg (KSSTA 2008)*
21 nonop vs 7 op, 10.1 yrs old; Nonop: 65% activity level, 50% copers, 9.5% meniscus

*Moksnes, Engebretsen, Risberg (JBJS 2012)*
Systematic review, Current level of evidence low

*Moksnes, Engebretsen, Eitzen, Risberg (BJSM 2013)*
Prospective cohort, n=46, 2 yr FU; 22% ACLr, 91% pivoting, 38% activity level

*Moksnes, Engebretsen, Risberg (AJSM 2013)*
Prospective cohort, n=40, iscus, 19.5% new meniscus, 33% surgery 11.0 yrs old, 3.8yr FU; 88% pivoting, 28.5% men
What about partials tears of the ACL? We see more partial tears of the ACL in children than adults. In adults, partial tears are usually functionally complete tears. We published a study where we looked prospectively at 45 children who had a partial tear of the ACL. We treated them without reconstruction, followed them four at a time to see who went on to need a reconstruction because of instability or further injury, and we found out that 31% of these kids went on to require reconstruction. We looked at risk factors and found that patients 18 and over did better than younger ones aged 9-14 (Fig. 5.1).

![Figure 5.1](image)

We also found that those who had a tear greater than 50% of the ACL did less well than those who had a tear smaller than that (Fig. 5.2). And we found that tears involving the posterobundle of the ACL did less well than those involving the anterobundle of the ACL (Fig. 5.3).
Figure 5.2

Log-rank test = 6.79, P = 0.009

Figure 5.3

Log-rank test = 6.76, P = 0.009
The problem with the ACL literature is that the studies are all relatively small series that are retrospective. And we don’t talk much about the amount of growth remaining. We often report patients by their chronological age. And I think it’s important to think beyond chronological age when we’re treating these patients.

It’s evident when referring to team photographs of young athletes that athletes of the same chronological age—both boys and girls—are often physiologically quite different, with some being much more mature than others.

So when we’re treating the younger patient with an ACL tear we need to know not just their chronological age, but also their physiological age—where they are in their growth and development. How do we establish that? We can do x-rays of their hand and wrist to determine their skeletal age. We can use the Tanner Staging System to establish where they are in their pubertal status.

It’s important to remember that the knee joint is very dynamic with growth during childhood and adolescence. The majority of growth in the lower extremities is coming from the two growth plates around the knee. As these kids are growing there are lots of other changes—changes in their coronal plate alignment, genu varum and genu valgum, changes in rotational plane alignment, femoral anteversion, and tibial torsion.

The concern we have when addressing ACL reconstruction in growing kids is growth disturbance, and in particular, the surgical procedure disrupting the growth plate.

There have been some animal models that have looked at this and some have shown that growth disturbances do occur while others show no such thing.
We reported in 2002 on 15 cases of growth disturbance from ACL reconstruction – 8 cases of genu valgum from growth arrest, 2 cases of leg length discrepancy, 3 cases of recurvatum, or hyperextension of the knee, from growth disturbance of the tibial tubercle growth plate, the growth plate that is involved with the occurrence of Osgood Schlatter’s disease.

Management and Complications of Anterior Cruciate Ligament Injuries in Skeletally Immature Patients: A Survey of The Herodicus Society and The ACL Study Group
Kocher et al (Journal of Pediatric Orthopaedics, 2002)

8 Cases: Distal Femoral Valgus with Bony Bar
- 3: Implants (Interference Screws) across Physis
- 3: Patellar Tendon graft bone block across Physis
- 1: Large (12 mm) Tunnel with Patellar Tendon graft
- 1: Over-the-Top Graft Placement

2 Cases: Genu Valgum without Bony Bar
- Lateral Extra-Articular Tenodesis

2 Cases: Leg-Length Discrepancy
- 2.5cm shortening (PT bone block across physis)
- 3.0cm overgrowth (6mm hamstrings graft)

3 Cases: Recurvatum with Apophyseal Bar
- Hardware across Tibial Tubercle Apophysis

When we reviewed these cases we developed some recommendations which seemed quite obvious – to avoid hardware, to avoid bony plugs across the growth plate, and to
consider modifying the technique based on how much growth the patient has remaining.

**Recommendations**

- Avoid Hardware across Lateral Distal Femoral Physis
- Avoid Hardware across Tibial Tubercle Apophysis
- Avoid Bone Plugs across Physes – Hamstring graft
- Avoid Large Tunnels
- Avoid Extra-Articular Tenodesis
- Minimal Over-the-Top Dissection & Notchplasty
- Consider Physeal Sparing Reconstruction in Prepubescent Patients

The images on the following page show two cases of growth disturbance after ACL reconstruction.

The first set of images show a 14-year-old male with normal alignment that was treated elsewhere with ACL reconstruction with allograft across the growth plates. At 10 months the graft failed, and he had valgus deformity of the knee (*Fig. 5.4*) at which time he was sent to us. We treated this with revision reconstruction of the ACL and we stopped the growth plate on the medial side of the distal femur to allow the outer side to continue growing to correct the genu valgum (*Figs. 5.5 and 5.6*). This patient has gone on to do well.
This next set of images is a 10-year-old male who was treated with a reconstruction across the growth plate and at age 16 was experiencing graft failure and substantial deformity of the leg – there is extensive valgus of the knee (Fig. 5.7). This represented a growth disturbance of both the distal femur but open on the proximal tibia (Fig. 5.8). This was a complex case. We had to reconstruct the ACL and do an osteotomy as well (Fig. 5.9).
Figure 5.10 below shows our algorithm for treating ACL injuries in children and adolescents. A large number of our patients are older adolescents with closing growth plates – females 14 and older, males 16 and older – with closing growth plates whom we can treat the same as adults because their growth plates are not an issue. Another large
group of our patients are adolescents who have reached puberty and whose growth plates are still open. This latter group we treat with reconstruction with a technique that does go through the growth plate. We use their tissue from their own hamstrings, not allografts. We keep the fixation away from the growth plates. Typically we use an interference screw on the tibia below the growth plate and an endobutton or some other technique on the femoral side above the growth plate.

We published our results of 61 cases using this technique. The average age was 14.7 ranging from 11 to 17 years old and we had good results with this procedure – a relatively low revision rate (3%), good functional outcome, and return to sports. We saw no growth disturbance by clinical and x-ray follow-up.

The prepubescent child is more of a challenge. We are now seeing more and more patients in this category. We do ACL surgery on a prepubescent about once a week now. They are being sent from all over the country. These are young kids – 8, 9, 10, 11-year-olds. The males tend to be under 12, while the females are 11 and younger. With these patients you can try PT and functional bracing. It may be that we’re seeing selection bias and the patients who end up in our clinic are referred because they’re having instability in the knee or they’ve torn their meniscus or articular cartilage.

What are the options in these very young patients? One option is to go through the growth plate as we do in the adolescents. But remember these kids have a lot of growing left to do. Another option is to just drill holes inside the epiphysis as has been described by our colleagues in Tennessee and Philadelphia. The advantage of this is that it’s more anatomic. The disadvantage is that you’re very
close to the growth plate on one side and very close to the articular cartilage on the other side.

We’ve advocated for a physeal-sparing ACL reconstruction technique using the iliotibial band that Dr. Micheli originally described (Fig. 5.11).

In this technique we left the IT Band intact – we bring it over the top and through the knee under the inter-meniscal ligament. So there are two components – an extra-articular component and an inter-articular component. And there are no drill tunnels across the growth plate. We published the results of this technique in 2005 and we are presently following up with more patients.

We had good functional outcome and as you can see, no issues with growth disturbance. Following is an image showing what the knee looked like two years later, both with arthroscope and MRI (Figs. 5.12 and 5.13).

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**Physeal-Sparing Combined Intra/Extra-Articular ACLr With IT Band**

*Micheli (Clin Orthop, 1999), Kocher Et Al (J Bone Joint Surg, 2005)*

- 44 pts (10.3 yrs old (3.6-14.0))
- 5.3 yr follow-up (2.0-15.1)
- 4.5% revision rate (4.7 & 8.3 yrs)
- IKDC: 96.7 + 6.0
- Lysholm: 95.7 + 6.7
- 21.5 cm growth (9.5 – 118.0)
- No growth disturbance
Figure 5.12

Figure 5.13
Studies have shown this procedure yields good biomechanical results.

The pediatrician will often tell you that a child is not a “little adult.” It is also true that a child or adolescent athlete is not a miniature adult athlete. We’re not just dealing with a downsized knee. Young patients are different physiologically and anatomically from their adult counterparts.

What about our outcomes with these procedures? I think we do quite well at restoring stability to the knee. Thanks to the PTs and ATs we are good at restoring ROM and strength. We get many of these kids back into sports. Many also fare well with symptoms and function.

What isn’t as encouraging is their long-term outcomes. I’ll refer to three studies that bear this out. The first of these studies at 15-year follow-up found that 80% of patients with ACL and other injury had signs of arthritis, and 62% of those with ACL injury alone had evidence of arthritis. The second and third studies also show high rates of arthritis at 8-15 year and 10-15 year follow-up.

**Oiestad Et Al (AJSM 2010)**
- Level 2, n=221, 15 yr follow-up
- ACL+ 80%, ACL 62%

**Sutherland Et Al (JBJS 2010)**
- Level 4, n=79, 8-15 yr follow-up
- 57% arthritis

**Oiestad Et Al (BJSM 2010)**
- Level 2, n=258, 10-15 yr follow-up
- 71% arthritis
As you can see, there are significant long-term problems with arthritis in kids who have had these reconstruction procedures.

So even though we have done well with some of the procedures, it’s important to remember that long-term outcomes can be problematic. That reinforces the importance of the research to find new and improved ways to treat the knee, and of course, to prevent these injuries from happening in the first place.
Suggested Readings


We all know the clinical importance of ACL injuries. Current estimates are that over a half million patients will tear their ACL every year. ACL injuries are certainly a cause célèbre and more and more books are being published on the topic. Currently our best approach to the ACL injury epidemic is prevention. But what if
despite all our best efforts and intentions a patient goes on to tear their ACL? Then, what do we do? What’s the best thing we can do right now to help our athletes, and what lies in store for the future of ACL treatment?

Today I’m going to talk to you about some new work that we’re doing to treat the ACL.

**ACL Reconstruction: the Gold Standard**

Back in the 1970s, we tried to sew the ACL back together to get it to heal – the so-called “primary repair,” or “suture repair.” Unfortunately, 90 percent or more of those patients who had this procedure went on to re-tear their ACL and have instability of the knee. So, that procedure was largely abandoned in favor of taking out the old ACL stumps and putting a graft of tendon across the knee to stabilize it – what we call an “ACL reconstruction.”

The ACL reconstruction is presently the gold standard. It’s a very good operation for getting patients to have a stable knee and back to sports. However, there are some problems with it, particularly in our adolescent athletes. In this patient population, teenagers who tear their ACL and have an ACL reconstruction have a much higher rate of tearing their graft than the average person; as high as 20 percent in the first two years. They also have a very high rate of graft failure later. So if we look at these patients 10 years out from their operation, the graft failure rate may be approaching 50 percent. In addition, they have a high risk of post-traumatic osteoarthritis – about 70 to 80 percent of patients. Whether they have a reconstruction or not, these young, healthy athletes are going to have arthritis in their knees at only 14
years out. And that means the 14-year-olds that I’m seeing in droves in my office and in the OR will have arthritis before the age of 30. And we don’t have answers for patients with bad arthritis of the knee who are under 30 years old.

The Potential Benefits of a New Surgical Intervention

The problems associated with ACL reconstruction are particularly problematic for young women. The peak age for girls to tear their ACL is between the ages of 15 and 19. That means many of them are going to have arthritis of the knee at an early age. (Fig. 6.1)

But what if instead of doing an ACL reconstruction, we put the ligament back together and put a biologic scaffold in between the two ends that would stimulate them to heal back together? In other words, what if we could get the ACL to regenerate? There are several reasons we think that might be more effective.
First of all, the ACL is a very difficult thing to replace with a graft. It’s a complex, fan-shaped ligament with broad insertion sites and different bundles that activate at different times according to how flexed (or bent) the knee is. We could preserve some of those properties if we get those ends to heal back together. Second, the ACL isn’t just a rope that ties the ends of the two bones together. It has proprioceptive nerve fibers in it, such that when the ACL starts to get stretched a little bit as the knee starts to go out of position, those nerve fibers send signals back to the hamstring muscles in the back of the thigh that act to pull the shinbone back and stabilize the knee dynamically, before the athlete is even aware that they’re doing it. That’s the proprioceptive function of the ACL. When we take out the old ACL and replace it, those nerves haven’t been shown to grow back into a graft. This important function may be lost when we do grafts. Third, we can also preserve some of the biomechanical properties of the ligament if we can get it to regenerate.

**What Makes the ACL Resistant to Surgical Intervention?**

In order to figure out a way to make the ACL regenerate, we first need to understand why the ACL doesn’t heal in the first place. Compare it to an MCL tear – most of the time you can put an athlete with a MCL injury in a hinged knee brace that simply protects and supports the knee and the MCL will go on to heal fairly uneventfully. No need even for surgery. But if that same athlete tears their ACL, it won’t heal, even with suture repair.
Why is that? They’re both ligaments. They’re both part of the knee. They are only about two centimeters apart. Why does one heal so well without intervention, and the other one not heal at all? So we did a series of studies looking at that, and basically comparing what happens in the MCL after injury and what happens in the ACL. How do the cells respond? How do blood vessels respond?

What we found was very interesting. We found that in both the MCL and the ACL, some of the basic biologic processes for successful healing occur in both tissues. The cells proliferate after injury and make more cells. The extracellular matrix or the protein of ligament - they make plenty of that material. And the cells are also able to migrate so they can migrate into a wound site. But unlike the torn MCL, the torn ACL lacks the bridge of scaffolding material that connects the two ends of the torn ACL and which would allow for effective healing.

**Bridging the Gap**

This made us ask the question: If bridging the wound site is what is needed to get the ACL healed, what if we surgically implanted a bridge between the two torn ends of the ligament that could hold those two ends together and serve as a bridge for those tissues to grow into and get the ACL to heal? The stitches would provide the support and the scaffolding would promote the healing. We call that concept “bio-enhanced repair.”

What to make the scaffold out of? To find out something that might work, we did a series of studies looking at various substances, measuring how the cells of the ACL liked each material, how the blood vessels would like it, and what the
response would be. We did things like take a basic scaffold and add different growth factors to it. We tried FGF2. We tried EGF. And what we found was adding individual growth factors was okay, but it really didn't give us the impact we were hoping for.

So we went back and looked at how wounds heal again elsewhere in the joint, such as in the MCL. All we have to do is make that happen now inside the joint.

So after we spent about a decade trying to figure out how to make the optimal scaffold and focusing in on the best cellular and growth factor additives, it turned out what tends to work the best for this application is just regular blood.

We wanted to test this in vivo. It’s fine to make things work in a test tube, but we had to see how it was going to work in the knee, which is a complex environment. So we started to study it in pigs. So we did a large general study with 30-kg pigs. We transected the ACL on both sides. On one side we used a suture repair, and on the other side we treated with suture and biologic scaffold made of platelet-rich plasma (PRP).

What we found was that if we only added PRP to the suture repair, it really didn’t make any difference. We found that the PRP will dissolve prematurely and go away before wound healing can occur, just like normal blood does.

### Building a Scaffold

What we came to realize is that we needed a carrier. We need something to hold the biologic factors, like PRP, in place so it wouldn’t be dissolved too quickly by that synovial fluid. We eventually discovered that if you use collagen, which is just a basic protein that the ACL is made of, and mix it with the fi-
brin in either blood or PRP, it forms a co-polymer that doesn’t get dissolved by blood or plasma. That collagen also activates platelets which starts the whole wound healing process.

What we now use is what is basically a protein sponge made of collagen and other important proteins in wound healing, and we put that between the two torn ends of the ACL and load it with our biologic factor. (Fig. 6.2)

So the basic concept is to use this protein scaffold, put it between the two torn ends of the ACL, add blood to the scaffold, and it soaks up the blood and holds it in the wound site, thus creating our bio-enhanced repair.

Testing Our Theory

The next step was to test this scaffold. And again, on one side we did suture alone, and on the other side we did suture plus the sponge plus PRP and looked at the various outcomes. These photographs show the outcome. (Fig. 6.3)

The first image shows the intact ACL. The middle photograph...
shows what the knee looks like if we just did a suture repair – when we went back in and looked at three months the notch was empty. There was no tissue there. The ACL repair had failed and the ends had resorbed. In the third image showing the suture plus scaffold, we see that at three months there is a nice fibrous bundle of tissue.

These images show the surgical technique for this process. (Figs. 6.4 and 6.5). We take an endobutton device with sutures attached to it, put it up through a small tunnel in the femur so the stitches are coming out through the ACL stump on the femoral side, and then we take the red sutures that you can see here and pass them through our sponge. Then we pull those red sutures down through the tibia which pulls the sponge into the area between the two torn ends of the ACL. And we can tie that over a button on the tibia. Then we connect the green sutures that are coming from the femoral

![Current Surgical Technique]

Figure 6.4

Murray, et al, Arthroscopy 2010
tunnel to those that we’ve placed into the tibial stump, and pull that up into the sponge. So the sponge is positioned in between the two torn ends of the ACL, with stitches to stabilize it. At that point we add the patient’s own blood to the sponge, which soaks it up and holds it in place.

Results of Bio-Enhanced Repair

We looked at the results of this technique in animal trials a year later. (Fig. 6.6) We saw that the results of bio-enhanced repair and ACL reconstruction were similar insofar as the mechanical properties were the same. We were encouraged that we had developed something that might be a somewhat less invasive for our patients. But the exciting and unexpected thing we found was what happens to the cartilage. In the ACL transected group of animals, at a year almost all of them had bad arthritis. This happened at a year in the animal...
models, whereas in patients it would probably take 14 to 20 years for it to happen. But it was in same pattern and in the same places. In the animals that we did the ACL reconstruction on, we saw this very similar cartilaginous changes as if we hadn't done any operation at all. Again, this is similar to what we see in our human patients. However, when we looked at the bio-enhanced repair results we didn’t find the arthritis. We’re not sure why. We always believed arthritis occurred because of mechanical instability in the knee. But because the mechanical properties and the mechanical behaviors of both treatment types were the same, we’re not sure why this group didn’t get arthritis – whether it was because we’re saving those proprioceptive nerves and keeping that dynamic stabilization of the knee, or whether it’s less invasive or because there’s something about using the biologic that helps protect the cartilage. We don’t know, but that’s the subject of important future study.
Introducing Bio-Enhanced Repair Into Human Subjects

Currently we’re on a pathway to try to establish how to introduce this to our human patients. We’re at design stage for our sponge and manufacturing and validation of this phase in hopes of eventually getting to a clinical trial.

We’ve also developed a non-invasive measure of efficacy using MRI that allows us to predict with 95% accuracy the strength of the graft or healing ACL repairs. That is going to be very helpful when we move to clinical adoption and determine whether this technique is working or not with these patients. We are manufacturing the product here under GLP compliant conditions.

Until we get there, what can we do? If a patient tears their ACL, we can still try to do the best possible ACL reconstruction we can do. We use autograft in our patients rather than allograft to minimize the risk of graft re-tear. We should start thinking about saving a torn ACL rather than removing it completely. Here at Children’s what we typically do is maintain the torn ACL pieces, make very small tunnels to fit that graft up through the middle of the remaining ACL in an effort to save at least some of those proprioceptive nerve fibers. We also want to make sure we avoid impingement. We have to think carefully about tunnel placement in our teenage girls especially. A lot of our teenage girls are able to hyperextend their knee so if you place your tibial tunnel for your graft anteriorly—as we often advocate for adults—those hyper-extending knees will stretch out the graft and cause problems. Another important area is rehabilitation after reconstruction – this is probably the most important factor in helping minimize these children’s chances of developing osteoarthritis. We also need
to monitor them for overuse – if they get pain and swelling after each time they play, they are probably not going in the right direction. We need to use a “return to play” criteria that is functionally based, and we’ll hear about that from Dr. Myers. The work of Lynn Sneider Mackler is also key in this area.

But what’s the best answer? You will hear it time and time again: *Prevention.*
Suggested Readings


Murray, MM, & BC Fleming.  
*Use of a Bioactive Scaffold to Stimulate ACL Healing also Minimizes Post-traumatic Osteoarthritis after Surgery.*  

Rodeo SA, SD Boden, MM Murray, & TA Einhorn.  

Biercevicz AM, MM Murray, EG Walsh, DL Miranda, JT Machan, & BC Fleming.  

Kiapour A, & MM Murray.  
Accepted for publication, Bone and Joint Research 2013.
Female athletes demonstrate a 4- to 6-fold increased risk for ACL injury compared with their male counterparts. This disproportionate ACL injury risk coupled with far greater sports participation by young women over the last 30 years has generated public awareness and fueled investigations on how to prevent these injuries.

One of the reasons I’m pleased to be part of anything the Micheli Center does is because of their focus on preventing injuries in the young athlete.
Why Prevention is Key

The great irony is that coaches and parents most often seek my advice on injury prevention after an injury has occurred. It’s time we made injury prevention a priority before an injury occurs. This is important for a variety of reasons. Aside from the pain, disability, and unhappiness our young female athletes experience after an ACL injury, there is also strong evidence that an ACL injury predisposes girls to developing osteoarthritis later in life. We are also learning that girls who sustain ACL injuries are also more likely to become overweight due to their reduction in calorie output. And as we all know, overweight and obesity are associated with a variety of serious medical conditions. Keeping our girls “in the game” will enable them to avoid those health problems associated with overweight and obesity.

Neuromuscular Control Deficits – The Most Significant Risk Factor

When we try to find ways to prevent injuries it’s important to identify risk factors. With young female athletes, the three main risk factors that have been identified are anatomical differences, hormonal fluctuations, and neuromuscular control deficits. Our research has indicated that the most significant risk factor is neuromuscular control deficits as this is the deficit that is modifiable.

The problem occurs with the onset of puberty. We see a trend where, unlike their male counterparts, the rate at which girls continue to develop their lower extremities levels off dramatically. Here is what we see:
• **Ligament dominance** – An imbalance between the neuromuscular and ligamentous control of dynamic knee joint stability, evidenced by the inability to control lower extremity coronal plane motion during landing and cutting maneuvers.

• **Quadriceps dominance** – An imbalance between knee extensor and flexor strength, recruitment, and coordination.

• **Leg dominance** – An imbalance between the 2 lower extremities in strength and coordination.

• **Trunk dominance “core” dysfunction** – An imbalance between the inertial demands of the trunk and control and coordination to resist it.

The result of these problems can be excessive joint loads that can put the knee into the highly vulnerable “valgus” position where an ACL injury typically occurs.

And at the same time as these problems become evident in young female athletes, the demands put on their lower extremities increase – they are getting bigger and heavier and the demands of their sports participation grows.

The image on the following page (*Fig. 7.1*) shows the knee going into the valgus position during dynamic loading, which we believe is due to neuromuscular control deficits referenced above.

We have investigated the relationship between neuromuscular control deficits and ACL injuries. The large-scale, prospective, 3-dimensional biomechanical cohort study we published in the American College of Sports Medicine in 2005 reported that the greater the neuromuscular deficits measured in female athletes, the more likely the occurrence of ACL injury.
Training to Address Neuromuscular Control Deficits

We are strong advocates of training to correct deficits in neuromuscular control as a means of reducing the incidence of ACL injuries. The foundation of any such program, we believe, is that it be deficit-based, not just a standard training protocol. The screening should help create the program.

It is also essential that any neuromuscular control program emphasize corrective feedback because unless the specific deficits are corrected then you will be hardwiring the deficits and poor mechanics.

We have a variety of training exercises to correct neuromuscular deficits. These include:

• Wall jumps
• Tuck jumps
• Broad jump and hold
• The 180° jump
• Single-leg hop and hold
• Squat jumps
• X hops
• Single-leg balance
• Bounding
• Jump, jump, jump, vertical jump

Many of these exercises are high-load involving power movements and we make sure they are taught and supervised properly.

Strength training with weights is a fundamental part of any training program to correct neuromuscular deficits. Dr. Micheli demonstrated in his landmark paper in the *Journal of Pediatric Orthopaedics* in 1986 that contrary to common wisdom, strength training for pre-pubescents was safe and effective with proper supervision, and shortly thereafter strength training for pre-pubescents was endorsed by most major healthcare organizations. Supervision and feedback is especially important for strength training with weights because of the potential for injury due to poor technique.

Our training program to correct neuromuscular deficits combines strength and skill development. Studies we have done have shown that this is a highly effective strategy.

The Importance of Beginning Neuromuscular Training Early

When should training begin? We find that the earlier these interventions start, the better the outcome for the athlete. This only makes sense since we are all aware that it is easier to learn something if you start earlier in life, and this certainly
applies to biomechanics. A study of 40 children who started neuromuscular training at seven years old had very good results, and it was important to note that the female subjects responded especially well. Evidence indicates that we should be starting these programs before puberty.

It’s appropriate to note that the Micheli Center is at the forefront of programs like these and they take a team approach to this kind of training – exactly the kind of training that will have positive results in preventing ACL injuries in young female athletes.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79305644
Suggested Readings

*Integrative Neuromuscular Training and Sex-Specific Fitness Performance in 7-Year-Old Children: An Exploratory Investigation.*

Myer GD, D Sugimoto, S Thomas, & TE Hewett.
*The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a meta-analysis.*

Myer GD, BW Stroube, CA DiCesare, JL Brent, KR Ford, RS Heidt, Jr., & TE Hewett.
*Augmented feedback supports skill transfer and reduces high-risk injury landing mechanics: a double-blind, randomized controlled laboratory study.*

Myer GD, AM Kushner, AD Faigenbaum, A Kiefer, S Kashikar-Zuck, & JF Clark.
*Training the Developing Brain, Part I: Cognitive Developmental Considerations for Training Youth.*

Myer GD, AD Faigenbaum, A Stracciolini, TE Hewett, LJ Micheli & TM Best.
*Exercise Deficit Disorder in Youth: A Paradigm Shift toward Disease Prevention and Comprehensive Care.*

Myer GD, RS Lloyd, JL Brent, & Faigenbaum AD.
*How Young is “Too Young” to Start Training?*
ACSMs Health Fit, 2013;J 17(5):14-23.

Myer GD, AD Faigenbaum, KB Foss, Y Xu, J Khoury, LM Dolan, TM McCambridge, & TE Hewett.
*Injury initiates unfavourable weight gain and obesity markers in youth.*

Faigenbaum AD, & GD Myer.
*Exercise Deficit Disorder in Youth: Implications for Fitness Professionals.*
ACSM’s Certified News, 2012;22(2).

Faigenbaum AD, & GD Myer.
*Exercise deficit disorder in youth: play now or pay later.*
Faigenbaum AD, A Stracciolini, & GD Myer.  
*Exercise deficit disorder in youth: a hidden truth.*  

Faigenbaum AD, A Farrell, M Fabiano, T Radler, F Naclerio, NA Ratamess, J Kang, & GD Myer GD.  
*Effects of integrative neuromuscular training on fitness performance in children.*  

*When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance health in youth?*  

*Integrative training for children and adolescents: techniques and practices or reducing sports-related injuries and enhancing athletic performance.*  

Myer GD, JL Brent, KR Ford, & TE Hewett.  
*Real-time assessment and neuromuscular training feedback techniques to prevent ACL injury in female athletes.*  

Faigenbaum AD, & GD Myer.  
*Resistance training among young athletes: safety, efficacy and injury prevention effects.*  

*A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength.*  

*Neuromuscular Training Techniques to Target Deficits Before Return to Sport After Anterior Cruciate Ligament Reconstruction.*  

Myer GD, DA Chu, JL Brent, & TE Hewett.  
*Trunk and hip control neuromuscular training for the prevention of knee joint injury.*  
Myer GD, KR Ford, & TE Hewett.  
*Tuck Jump Assessment for Reducing Anterior Cruciate Ligament Injury Risk.*  

*The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics.*  

*Neuromuscular training improves performance and lower-extremity biomechanics in female athletes.*  

Myer GD, KR Ford, & TE Hewett.  
*Methodological approaches and rationale for training to prevent anterior cruciate ligament injuries in female athletes.*  

Myer GD, KR Ford, & TE Hewett.  
*Rationale and Clinical Techniques for Anterior Cruciate Ligament Injury Prevention Among Female Athletes.*  
We just had an excellent presentation by Greg Myer who showed us the incontrovertible evidence that appropriate training can prevent ACL injuries in young athletes, and especially girls. I can tell you from personal experience that this works – my daughter’s soccer team has been engaged in an ACL prevention program for several years and last year her team experienced only one ACL injury, whereas the girls team a year older who did not have such a program saw four ACL injuries in their ranks. So in other words, I’ve read the studies and I’ve also seen the evidence first-hand.

The following text is a summary of the oral presentation made by Mr. Gustafson at the First Annual Micheli Lecture.
But what is significant is that despite all the evidence out there, very few sports programs have such programs in place. In fact, I did an informal survey recently and found that of all the sports coaches I asked — from Division 1 college to Division 3 high school — not a single one had an ACL prevention program in place. That is highly unsatisfactory, in my view.

It’s therefore worth giving some thought to how we can get school and community-based sports programs to adopt these proven ACL prevention programs.

How to Get a Program Accepted

As a health professional who’s also the parent of a young female athlete, I can tell you it’s relatively easy to work one-on-one with your daughter on neuromuscular control. If you’re coaching a team and you know the program then you can implement it at the beginning or end of a sports practice. But what about if you’re on the outside? If you’re a health
professional trying to get a school or community sports program to adopt an ACL prevention program it's a lot more of a challenge because there's often the suspicion that you’re just trying to drum up business. If you are a parent who is also a healthcare professional then the key is to go to the meeting as a parent first and a healthcare professional second, in which case there is a stronger likelihood you’ll be successful.

Which Program is Most Attractive?

There have been several gold standard programs developed over the last few years. SportMetrics is Greg Myer’s program based in Cincinnati. The PEP program was developed by Dr. Mandelbaum in California. And then there is the FIFA 11 program.

In evaluating the programs, it becomes clear that the programs with the better injury prevention outcomes are those that are more comprehensive – in other words, they involve strengthening, agility, jump training, balance, and flexibility. A comprehensive program is also better suited to preventing injuries other than those of the ACL – there’s patellofemoral pain, Osgood Schlatter’s Disease, Sever’s Disease, and patellar tendinitis. To be able to explain that a comprehensive injury prevention program targets not just the ACL but these other conditions will make it more likely it will be accepted by those making the decision.

The SportMetrics and PEP programs have a much better emphasis on developing flexibility than FIFA 11. FIFA 11 gets a lot of support from the professional players but when you look at the content, it’s clear there isn’t much stretching in
it. For younger athletes who are growing fast, flexibility is especially important because they tend to be quite “tight.” This lack of flexibility predisposes them to a host of the injuries I mentioned before, not just ACL injuries.

In the 25 years I’ve been working with young athletes I’ve found Greg Myer’s papers to be really helpful in understanding ACL injury prevention in young athletes. And one thing that has become obvious is the need for qualified supervision of these programs.

ACL injury prevention programs range from 9 minutes to 90 minutes. Some of the off-season programs do indeed last for 60-90 minutes but that’s not for everyone. A lot of kids are playing three sports and are very busy. But with a 10-minute program if you can statistically show that you are reducing ACL injuries then you may be able to pitch that program more successfully than you could a much longer program.

The downside of these shorter programs is that you can’t get the kind of strength benefits you need for neuromuscular control. For these you need the longer off-season programs that are better for building strength.

When we try to convince coaches to make these neuromuscular control programs part of their practices, their main objection is the amount of time it takes. So when you tell a coach—whether it’s a school coach or community sport-based coach—that the session will last from 20-25 minutes, they will often respond that they can’t commit to that time frame. But when you bring it down to the 10-minute program we get much more positive responses.
How Do You Break Into a Town Sports Program?

It’s a challenge to introduce a sports injury program into a town’s community sports program. To do it in Medfield, MA we had to overcome people’s impressions that 1) there wasn’t time for the program, and 2) the kids were too young to need it – that kids this young “didn’t get injured”. We showed decision-makers certain studies such as the Brazilian Osgood-Schlatter’s study that injuries can be prevented. We demonstrated that dynamic warmup including flexibility exercises really helped injury prevention in kids aged six, seven, and eight and the coaches bought into it and agreed to do the program before practices (Fig. 8.1).

![Figure 8.1](image)

When the kids got to the under-9s and under-10s level we got the coaches to start implementing ACL injury-specific agility training such as running “cuts” while at the same time
maintaining flexibility to prevent the kinds of injuries see in this group – tendinitis, apophysitis, patellofemoral pain, and the like (Fig. 8.2).

When we got to the under-10 to under-14 age group we started adding to the dynamic warm-up exercises plyometrics and strength training to strengthen the athletes’ legs (Fig. 8.3). And as I stated right up front, we saw a very low incidence of ACL injuries – just one as compared to the four ACL injuries unfortunately seen in the girls who had been in the program the year before who did not have the benefit of this program.
What we were trying to do was implement a program that would work, that the parents would support, and ultimately addressed the neuromuscular deficits the athletes generally faced. Although we didn’t have the resources to provide individualized care to target a specific athlete’s deficits, we were certainly able to steer those athletes to places like the Micheli Center where they could receive that level of individualized care.
The work that has been done by people like Greg Myer has created a reversal in policies toward training children. For example, the NSCA used to maintain that a child couldn’t do plyometrics until they could squat one and half times their body weight. But that’s been revised and now the NSCA’s position is that children can safely do jumping and leaping type exercises characteristics of plyometrics and neuromuscular training. Our belief is that these types of exercises are indeed beneficial when they are done under the supervision of healthcare professionals and they can be instrumental in preventing ACL injuries in young athletes. And we urge you to work with school and community-based sports programs to adopt them.

Dr. Gregory Myer demonstrates ACL assessment following Mr. Gustafson’s presentation.

A full audiovisual record of this presentation—including an ACL assessment demonstrated by Dr. Gregory Myer—is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79276430
Suggested Readings


The organizers of the First Micheli Lecture were honored to have as the event’s keynote speaker Lars Engebretsen, MD, PhD. Dr. Engebretsen is a professor and Chairman of the Orthopaedic Department, Oslo University hospital and University of Oslo Medical School, and professor and co-chair of the Oslo Sports Trauma Research Center. He is also Chief Doctor for the Norwegian Federation of Sports, and headed the medical service at the Norwegian Olympic Center until the autumn of 2011. In 2007 he was appointed Head of Science and Research for the International Olympic Committee (IOC). Dr. Engebretsen’s main area of research is resurfacing techniques of cartilage injuries, combined and complex knee ligament injuries, and as he describes in his presentation at the First Micheli Lecture, prevention techniques of sports injuries. He is the Editor-in-Chief for the new IOC-BJSM journal: Injury Prevention and Health Protection and Deputy Editor for JBJS. In addition, he serves on several major sports journal editorial boards and has published more than 300 papers and book chapters.
THE KEYNOTE ADDRESS

Sharing the Experiences of the Oslo Sports Trauma Research Center

Lars Engebretsen, MD, PhD
Professor and Chair, Department of Orthopaedic Surgery, Oslo University Hospital and Faculty of Medicine
Co-chair, Oslo Sports Trauma Research Center
Head Scientific Activities, International Olympic Committee (IOC)

The following text is a summary of Dr. Engebretsen’s keynote address at the First Annual Micheli Lecture.
By 2000 I had spent many years in orthopedic clinical research and as an orthopedic surgeon, but it was a sports injury event in that year that deeply affected my home country of Norway that caused me to turn my focus to sports injury prevention.

This event was when the captain of our women’s team handball team tore her ACL and was unable to participate in the Sydney Olympics that year. Because team handball is practically our national sport this was big news in our country. Her injury sparked a parliamentary debate which quickly became an inquiry into why so many young women tear their ACLs. The end result was a major grant from our government to study ACL injuries and the establishment of the Oslo Sports Trauma Research Center (OSTRC).

With the Micheli Center having just been founded, I thought it would be helpful to share some of our experiences in preventive sports medicine to help you understand what you have to look forward to as you grow and flourish.
In 2000 the OSTRC was launched to prevent injuries and other health problems in sports through research on risk factors, injury mechanisms, and prevention methods, with a particular focus on football, team handball, and alpine skiing/snowboarding, and on the most common and serious injury types. Later on research sports illnesses such as eating disorders, and sudden cardiac death has been added.

Every ACL injury that occurs in Norway is registered with the OSTRC. So far that is 16,000 ACL tears. And we follow the patients who’ve suffered these injuries so we can do long-term surveillance.

We don’t just focus on Olympic athletes, and in fact most of our research has been done in younger patients aged 14-18.

In addition to orthopedic surgeons, we are staffed by physical therapists, physiotherapists, 20 PhD’s, 20 masters students, and many additional support staff.

One of the most important components of the OSTRC is to have people visiting from other countries. Sports medicine is truly an international field. With Norway being such a small country, we naturally rely on expertise from outside to supplement our own. Every year we welcome sports medicine professionals from 4 or 5 different countries who do work at our facility.

One of the main drawbacks of the thousands of research papers published on sports injury prevention every year is that very few of them actually provide prevention strategies. Of the 2000 or so papers published last year only 6 described the efficacy of preventive measures or their implementation.

This is why we are proud the OSTRC is in the forefront of that field. In 2009 we were selected to be an IOC Research Center for Prevention of Injury and Protection of Athlete
Health, one of only four such centers in the world. The work being done at these centers is extremely interesting and important (Fig 9.1).

At the **Sport Injury Prevention Research Centre (SIPRC)** at the University of Calgary, Canada, they are looking at the impact of bodychecking on injuries in youth hockey, and have made important discoveries in that area.

At the **Centre for Injury Prevention and Safety Promotion (CIPSP)**, School of Human Movement & Sport Sciences, University of Ballarat, Australia, they are looking at ways to implement prevention strategies (Fig. 9.2).

At the **UCT/MRC Research Unit of Exercise Science and Sports Medicine (ESSM)**, University of Cape Town, South Africa, they are looking at ways to prevent overuse injuries and also how to prevent injuries in Paralympic athletes.
When the Micheli Center develops it would be helpful to develop partnerships with other centers to develop knowledge, including centers around the world.

Much of our research at the OSTRC has been in investigating ACL injuries – particularly in team handball and downhill skiing. One of our most exciting initiatives has been to develop computer models showing the precise mechanism of ACL.
Much of the research at OSTRC has been in investigating ACL injuries – particularly in team handball and downhill skiing.

Based on our research we have also developed our own exercise protocol for helping prevent injuries. Our program needs to be done by athletes three times a week for between 10 and 15 minutes per session. We have found this program to be extremely effective. In one study we found that team handball players were 16 times more likely to sustain an ACL injury if they did not do the program. And in a separate study we found that we could reduce ACL injuries by 30% and all lower extremity injuries by 50% by doing this program (Fig. 9.5).

We are less convinced that our American colleagues that it is possible to identify “at-risk” athletes. We have found that many athletes who do not show neuromuscular control deficits are also at risk.
What is not up for debate is whether prevention programs work. Indeed, we’ve seen in Norway that when we put pressure nationally on coaches to do these prevention programs that injury rates go down, and when we relax the pressure the injury rates go back up again.

What this tells me is that the main thing lacking in our research is finding out how to get ACL injury prevention programs like the ones we’ve been talking about implemented. This is an area that needs to be a focus.

I only have to look around the room to see all of you here to know that there is the will to put into practice the knowledge we now have at our disposal.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79297589
I’m here to discuss current management of concussions. From an overview standpoint, it’s important to state right up front that the biggest challenge facing all of us who deal with concussions on the sideline—coaches, trainers, clinicians, and other allied health professionals—is identifying those marginal concussion cases.
It’s relatively straightforward to identify obvious concussions symptoms, particularly those that include loss of consciousness. But it’s identifying those athletes who have suffered a milder concussion and taking the appropriate steps to manage that athlete that is much more challenging. And it’s extremely important that we have a plan in place to do this because of the potential negative consequences of concussions whether mild, moderate, and severe. If we miss a concussion or the athlete fails to report it and continues to participate in sports, the dangers of another impact to the head before recovery can be very severe.

We’ll talk about some of the tools we use to identify concussion a little later. Let’s now discuss management of athletes identified with concussion.

Five Areas Of Concussion Management

• Pre-season
• On the Field
• Off the Field
• Return to Play
• Prevention

Pre-season Management

Concussion management starts preseason and I think this was also touched on earlier in the morning when the pre-participation exam was discussed. Dr. d’Hemecourt mentioned cardiovascular review and concussion review, and it’s certainly true you want to look and see if there’s concussion history. Some questions that should be asked in the history: How many concussions have there been? What was the
mechanism for each? What was the length of time that the recovery, and are there any residual symptoms?

The history is important because there are other factors that are important besides the number of prior concussions. Equally significant is a pattern where the athlete is getting injuries from multiple concussions, or from lower and lower energy collisions, or longer and longer time for recovery after each of those injuries.

The pre-season evaluation should include some baseline data testing. We use preseason computerized neurocognitive testing. But they are not necessarily appropriate for the sideline use, when you need to make that quick decision. We certainly use them for clinical follow-up, in assessing when the athlete is ready to return to practice and games.

Sideline Management

For sideline assessment, you really have three tools. First, you can get a subjective survey of the athlete. There is also the physical exam, including balance testing. But with balance testing, every athlete is different. So the balance testing, you use BESS testing which is testing their balance on both feet, tandem stance, and standing on one leg; counting the number of corrections at each position while standing for 20 seconds with their eyes closed. But every athlete is different, so having that baseline is helpful.

And third, you can test their cognitive function. The (Standardized Assessment of Concussion) SAC card that I use is a pretty challenging neurocognitive test, and so student athletes are typically not going to score perfectly on it, even when they’re healthy. That’s why it’s helpful to know their
preseason score so you have a baseline, especially when assessing marginal cases where concussion may not be immediately obvious.

So the whole sideline team—clinicians, coaches and of course even the athletes—should be familiar with current management. The International Consensus Statement (currently the 4th edition) is one of the most helpful resources, and that has in it the assessment tool that we use, SCAT-III. I keep a laminated copy of SCAT III in my pocket for when I’m working sideline (Fig. 10.1).

![Table 2. Standardized Assessment of Concussion (SAC)](image)

**Figure 10.1**
I’ll do this sideline test for every athlete where concussion is suspected, but if there are clear symptoms that are still present by the time we’re doing this testing, or there’s clear reason to think they have even marginal concussion, the athlete is not going to go back to that contest, regardless how well they do on this test. That’s the commitment we made as we have refined our ideas about concussion, as referenced in the International Consensus Statement. For younger athletes in particular, no longer is it acceptable to let them return to play if the symptoms clear within 15 or 20 minutes, which used to be standard. We used to say, “Well, if it clears within 15 to 30 minutes, depending on which system you’re using, they might be able to go back to the contest.” But we have since made a commitment that if there are symptoms of concussion, even if it’s brief, or they had their “bell rung,” so to speak, they shouldn’t go back to that contest.

What about marginal cases? This might be when they got hit hard and the coach sends them over to me and wants them assessed. We’ll do the cognitive tests at rest. Then we’ll get their heart rates up, and see if symptoms are present with exertion. We assess the physical exam including balance testing, and do cognitive testing – typically with the SAC.

It’s important to do honest and clear assessments. If I’m being overly cautious and taking all the athletes out of the game after any hard hit, the coach will stop sending them over to me, or the athletes will stop self-reporting.

On the field we need to recognize that all coaches and clinicians should be trained to recognize symptoms on the field, most commonly headache. Loss of consciousness is much less common involving less than 10 percent of concussion injuries. Sometimes symptoms involve a subtle change in performance.
Recognizing Immediate Concussion

Symptoms on the Field

- Confusion, Amnesia
- Headache, Drowsiness
- Loss of consciousness
- Ringing in the ears (tinnitus)
- Nausea, Vomiting
- Blurred Vision, Unequal pupil size
- Convulsions
- Unusual eye movements
- Slurred speech
- Change in Performance

Delayed Signs and Symptoms of Concussion

- Irritability
- Headaches
- Depression
- Sleep disturbances (insomnia, difficulty waking)
- Fatigue
- Poor concentration
- Trouble with memory
- Getting lost, easily confused
- Sensitivity to sounds, lights and distractions
- Loss of sense of taste or smell
- Difficulty with gait or coordination

Delayed symptoms might be headaches later on, difficulty in school that week, sensitivity to light and noise, or change in sleep patterns.

When it’s recognized as a concussion, we take them off the field. Not every athlete will necessarily go to the Emergency Department, but we would certainly send to the ER those athletes who need urgent evaluation or urgent imaging – specifically CT scan. CT scans are indicated for those who show signs of intracranial hemorrhage or fracture, or those also with prolonged loss of consciousness. Typically prolonged loss of consciousness is defined as more than a minute, but if you’ve ever been on the sideline next to someone with loss of consciousness, a minute feels like an eternity. So I would say, practically speaking, if there’s any confirmed loss of consciousness or seizure activity, the athlete should probably have imaging.

After making the diagnosis of concussion I’ll check them on the sideline after 15 minutes and half time and end of the game. If they’re
When to Send to the ER

- Prolonged loss of consciousness, seizure
- Worsening symptoms or lethargy
- Focal neurologic deficit

worsening, despite rest, we’ll consider sending them to the ER. That also applies if there are multiple deficits on their exam.

Off the Field Management

Once we identify a concussion, it’s important that we plan for outpatient reassessment with parents, the school, and clinicians.

The most important and overriding management tool is REST. This involves both physical rest and cognitive rest.

**Physical rest** starts with removing athletes from contact sports and also ensuring they don’t participate in higher risk sports until they’ve recovered – activities such as snowboarding, skiing, skateboarding.

It’s important to recognize that there can be some negative consequences of this, just like there might be with certain medications. When we institute aggressive physical rest for too long, we must be aware that physical de-conditioning can occur, often as early as two to three weeks into the recovery course. Sleep schedule may also be affected. If they’re home from school sitting on the couch and/or sleeping during the day, they may not sleep well at night and they’ll be exhausted during the day. From that sleep interruption they may have their concussion symptoms exacerbated, especially irritability, trouble concentrating, and headaches.

So we have to be careful with how much full physical rest we give them and I often like to try to get them involved pro-
actively in their recovery. I like to get them stretching and walking early in the course. Later on we’ll talk about increasing exercise challenges.

**Cognitive rest** is important too. We try to do aggressive cognitive rest, or aggressive shutdown. We often recommend some time out of school for those athletes who are significantly symptomatic. Sometimes three to five days out of school. But I personally prefer try to reintroduce some degree of structure to the day. We might try to reintroduce some degree of light to moderate cognitive challenge, even before they are totally symptom-free, because we want to make sure we’re not contributing to the psychologic stress from missing school. That’s because we see many student athletes who get stressed not just from missing practice or the big game, but also because they’re missing schoolwork. Conscientious students tend to be very conscious of how much school work is building up and how much they’re going to have to make up, especially in the high school years. They’re very aware of their college applications being built up by performance. Because it’s a big stressor when they’re out of school we want to make sure we do appropriate aggressive cognitive rest, but we have to find the right balance. And again, we certainly want to keep those athletes out of contact sports until there’s full recovery, but we have to make sure we keep prevent excessive de-conditioning.

We’ll talk a little later about other treatments for concussion other than physical and cognitive rest and we’ll also look at return to play criteria for the prolonged recovery.
Outpatient Assessment

- Out of games/practices until full clearance
- Avoid recreational activities with risk of accidental collision/fall
- Optimize sleep, hydration, nutrition and avoid prolonged digital exposure
- Full cognitive rest may require time out of school and academic accommodations (partial workloads, half days at school, longer time for projects/tests etc.)

Then we want to plan for outpatient assessment, the period during which they’re going to be seen and formally assessed and formally cleared once they are recovered.

We want to be in communication with the parents, of course. Once the patient is home, we tell parents we want them out of games and practices and to avoid other activities like skateboarding where there might be accidental collisions. I tell them to try to optimize everything that might potentially promote recovery: including good nutrition and hydration.

Return to Play

When they recover, there are four criteria we look at when considering return to play.

- Resolution of symptoms at rest (measured with Post Concussion Symptom Scale)
- Academic Tolerance
- Exercise Tolerance
- Neurocognitive Test results (where applicable)
Let’s look first at “resolution of symptoms.” Refer to the symptom score that we use in the office (Fig. 10.2). It’s taken from SCAT-III which is available in the International Consensus Statement, which I think is a “must read” for folks who are here thinking about continuing medical education.

So 0-6 for symptoms: they should circle any symptoms that are different than their baseline. If they always have trouble sleeping, and that’s the same as usual, it’s typically a zero. If they never had trouble sleeping, and now they can’t get to sleep, they’ll score whatever it is. We want that back to zero before they return to contact.

Academic tolerance is next. After concussion symptoms have resolved we want to make sure they have full academic tolerance. They must be able to tolerate full days of school, full schoolwork, feel well when they’re really studying hard and have similar grades that they had before the injury.

Third, we expect exercise tolerance. They start with stretching and walking fairly early on in the course. But once symptoms have resolved, and academics are tolerated, then we start with low, medium then high intensity non-contact exercise. Biking, elliptical, things like that. I tell them, for a rule of thumb, low to medium intensity exercise is where we can just about talk to each other if we’re sitting on bikes next to each other. Then when they graduate to medium and medium-high intensity exercise, then you have to just about take a breath if we were trying to have a conversation with each other. And then high intensity is full-out sprints, or push-ups, things like that. So we expect progression from low, medium, and high – exercise without symptoms during or after the exercise.
<table>
<thead>
<tr>
<th>Symptom</th>
<th>NONE</th>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
</tr>
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<tbody>
<tr>
<td>Headache</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>“Pressure in head”</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Neck pain</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Balance problems or dizziness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Vision problems</td>
<td>0</td>
<td>1</td>
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<td>3 4</td>
</tr>
<tr>
<td>Hearing problems / ringing</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>“Don’t feel right”</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Feeling “dinged” or “dazed”</td>
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<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Confusion</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Feeling like “in a fog”</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Fatigue or low energy</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>More emotional than usual</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Irritable</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
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<td>3 4</td>
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<td>Difficulty remembering</td>
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<td>1</td>
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<td>3 4</td>
</tr>
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<td>Sadness</td>
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<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Nervous or anxious</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Sleeping more than usual</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
<tr>
<td>Other: ___________________</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3 4</td>
</tr>
</tbody>
</table>

*Figure 10.2*
Depending on age, if it's a professional athlete or college athlete with no prior history, and brief symptoms two or three days, we can progress them fairly quickly through each stage, one or two days, perhaps. If it's a high-school aged kid with maybe a prior concussion last year, we may be a little more conservative, maybe three or four days for each of those low, medium and high intensity stages.

With the first three criteria satisfied, we may then use that SAC score or computerized testing to see if the neuro-cognitive function is really recovered. For recovery, beyond four weeks or more, we're considering physical therapy. We’re looking for other causes, like trigger points, or myofacial pain or whiplash, muscular headaches. Sometimes off-label medications are being used by clinicians, but that’s a bit more advanced and specialized.

**How Many Concussions is Too Many?**

The question of “How many concussions is too many?” is one that comes up frequently from parents and coaches as well.

The answer is unknown. There are some indications that multiple concussions might cause conditions like chronic traumatic encephalopathy. When evaluating multiple concussions, we have to ask whether the injuries are occurring with
decreasing force, requiring longer recovery times, or causing persistent deficits in cognition. In those situations we need to be thinking about perhaps taking a year out from sports to insure good academic performance and allow physical matur- ity, or considering retirement from the sport all together. But as you all know, these are complex and difficult discussions because, for serious athletes, these are not small decisions.

Finally, it’s important to remember that young athletes are particularly vulnerable. They have unique responsibilities, separate from the pro athletes. They really have two jobs: they have academics and they have sports- and often they take both very seriously.

So the take-home message is that there should be a low threshold to sit athletes out from sports. Physical and cognitive rest is the cornerstones of treatment. There should be an organized, clear, return-to-play plan that everyone can follow consistently. And if there are prolonged symptoms, consider referring to an expert.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79333581
Suggested Readings

McCrorry et al.
SAJSM vol 21 No. 2 2009
http://www.cdc.gov/concussion/index.html

Halstead et al.
Returning to Learning Following a Concussion.
Pediatrics. Volume 132, Number 5, November 2013

Meehan WP III, & RG Bachur.
Sport-Related Concussion.
Pediatrics 2009;123;114-123

Meehan, William P.
To answer that all-important question: 
Yes, it is possible to prevent concussions. 
There have been multiple ways proposed 
to do this, and I’m going to start by 
reviewing these and how effective 
they are.
Education and Legislation

This isn’t a way of preventing concussions from occurring in the first place. This is part of a strategy to prevent the *sequelae* of concussions. If everyone involved in the athletic contest is better able to recognize concussions—coaches, trainers, athletes, and parents—then we’ll be better prepared to remove the athlete and prevent further risk of the cumulative effects of a prolonged recovery and second impact syndrome. But of course, this isn’t a way of preventing concussions from occurring in the first place.

Personal Equipment

Within three years of helmets becoming mandatory the rates of high-sticking penalties tripled. This gets a lot of attention too. But there are major misconceptions in this area. Perhaps most important, *helmets do not prevent concussions*. This can be a difficult concept to grasp. Concussions are caused by a rapid spinning of the brain after impact, not the impact itself. To impact the brain tissue there would have to be force sufficient to deform the helmet, then the skull, and finally the brain – and fortunately this is very rare in sports. Instead what happens is that the athlete gets hit in the head and the head spins, thus causing the concussion. The same applies to mouth guards. I want to emphasize that helmets do prevent catastrophic brain injury and mouth guards do prevent dental and facial bone injury, the purposes for which they were designed, and so all athletes participating in sports that require their use should wear properly fitted, undamaged helmets and mouth guards.

It is correct that the inside of a helmet is typically lined with foam or air cells. And so at the time of the impact the cushioning substance will compress and decrease the impact force before it reaches the head – slightly. But this slight
decrease in force does not appear to decrease the resultant spinning of the brain enough to decrease the incidence of concussion. There might be a handful of concussions prevented with personal protective gear, but those numbers are not statistically significant.

Another important consideration is that behavior changes in response to protective equipment. For example, it wasn’t so long ago that there were no helmets in the National Hockey League. Eventually they became mandatory – and within three years of helmets becoming mandatory the rates of high-sticking penalties tripled. In addition, they had to invent the penalty of “boarding” to stop players from throwing their opponents head-first into the boards. Prior to that players didn’t do this because they knew what the injury consequences were if they did so.

And so the bottom line is when you introduce helmets to a sport the rates of concussion are more likely to increase than decrease.

And yet it seems logical to want to push for the introduction of helmets to make a sport safer. It’s true they prevent catastrophic head injuries but the price you pay is more concussions. Perhaps future technologies can reduce the rates of concussions, but there is little evidence that current models are effective in this regard.

One of the main reasons I want to make this point is that there is a push to introduce helmets into girls’ lacrosse. I am strongly opposed to this. In the medical literature, I am unaware of a single reported case of catastrophic brain injury in girls’ lacrosse. The introduction of helmets would prevent something that appears not to be happening, and the price would be a likely increase in the number of concussions.
The same thing applies to mouth guards. There are two studies in the *Journal of Dental Traumatology* that people reference all the time. They supposedly demonstrate that mouth guards reduce the risk of concussion. We hear people cite these studies all the time. They took two cadavers, fit one with a mouth guard, then hit both the cadavers on the head with a sledgehammer. They measured less damage in the cadaver wearing the mouth guard. But when you consider that concussion is a *functional* problem, how could a test on cadavers possibly be considered useful?

I believe the same thing that applies to helmets applies to mouth guards too. If you hit someone on the chin, a mouth guard will decrease the amount of force slightly before it gets to the brain – remembering of course, that if they get hit anywhere else then the benefits don’t exist. But for the same reasons described above, mouth guards will decrease the incidence of concussion in a very small number of people and have not significantly decreased the overall incidence of concussion.

**Collision Anticipation**

This is another key issue. A colleague of ours, Jason Mihalik, did a study of bantam age ice hockey players in which he measured “collision anticipation.” He and his team videotaped numerous games at this level and recorded what happened when players got concussions. They correlated collision anticipation with severity of concussion. Here’s what they found. When athletes saw and anticipated the collision, they flexed their hips and knees and drove through the impact, resulting in relatively low rates of concussion. When they saw the collision coming but didn’t have time to brace...
themselves, the concussion rates were higher. And when they didn’t see the collision coming at all, the concussion rates were highest.

In other words, anticipating the collision will reduce an athlete’s likelihood of sustaining a concussion.

As many of you will have noticed, as a player gets older and more seasoned, they look up more when they get into tight situations such as competing for the puck in the corner, which reduces their chance of a concussion.

**Conditioning**

Some of the most interesting work on the relationship between conditioning and concussion has been done by Dawn Comstock, someone we have worked with a lot. Dawn has a huge cohort of male and female athletes of all different levels in 200 high schools across the country.

Recently she did a study that involved measuring neck strength and head/neck circumference and what the relationship was to concussion rates. What the preliminary data shows is that athletes with stronger necks have the lowest rates of concussion. Secondary analysis shows that beyond a certain threshold, for every pound of resistance young athletes increased in their neck muscle strength, the risk of concussions decreased by 5%.

That’s why I believe that conditioning—and in particular strengthening the neck muscles—is an important way to prevent concussions.

And if you think about it, it makes sense. Concussions occur as a result of the rotation of the brain after impact. The
stronger your neck muscles are, the more rigidly they attach your head to the rest of your body, and so the less severe that rotational action is going to occur after impact.

What hasn’t yet been proven is that if you take athletes with weaker neck muscles and strengthen those muscles, the risk of concussion goes down. But even though that hasn’t yet been proven, we encourage athletes to strengthen their necks.

**Rule/Eligibility Changes**

This certainly seems like an effective way to reduce the risk of concussions. However, there will always be unintended consequences. For example, there is a push to lower the age at which we start kids in contact sports. No full-contact football until you’re 15. No checking in hockey until you’re 15.

I understand the logic behind this. However, I don’t believe it’s a good idea. I think it’s far preferable to introduce collisions at a younger age, in a controlled setting, before the athletes are big, strong, coordinated, and can generate considerable force. What the USA Hockey has said is that we’ll prohibit checking in competition until the players are older but we’re going to initiate training at a younger age to teach athletes how to avoid a collision and how to absorb a collision without rattling your head, both on and off ice, in a controlled setting. This is a far safer way to do it.

If you don’t let kids start playing football until they’re 15, consider what happens—they’re going to start playing as sophomores, and they’re going to come up against 240-lb seniors who might already have been playing for a few seasons—and that’s going to have consequences.
We need to teach football players to absorb a tackle properly, how to deliver a tackle properly, how to get out of the way of a tackle at a younger age – ideally in a controlled setting.

Now let’s look at soccer. Some people say we shouldn’t let kids “head” the ball until they’re 15. I’m against that. After all, some players can kick the ball pretty hard at that age. You don’t want to learn how to head the ball against other 15 year olds blasting the ball at you. It might make sense to start young kids learning to head a “nerf ball” at a younger age, again in a controlled setting. This way kids can learn to move their heads to the ball instead of the ball hitting them unexpectedly in the head. They can develop the neuromuscular control, timing, and coordination required to head the ball using proper technique.

**Rule Enforcement**

There have been several studies that have assessed the effect on injury rates of changing the rules and enforcing the rules. One study is of particular interest. It was by Bill Roberts, who is famous for his work in sports medicine. His study looked at the so-called “fair play” rules in ice hockey.

In this system teams receive sportsmanship points to teams so that each team’s ranking is influenced not just by wins and losses but also sportsmanship. They set a threshold of “normal” penalty minutes. If a team was below that number of penalties, it would get points that counted toward its standing. If a team was above that number of penalty minutes, points were deducted. What happened was that injury rates went down significantly as penalty minutes decreased. This highlights the role of rule enforcement in injury prevention.
For the reasons I have described, I therefore propose that we not focus on equipment or age restrictions for contact, but instead on rule changes, enforcement, conditioning, and training.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79300791
Suggested Readings

*Fair-play rules and injury reduction in ice hockey.*  

McCrory, P, et al.  
*Consensus Statement on Concussion in Sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008.*  

Meehan, WP, 3rd, P d’Hemecourt, & RD Comstock.  
*High school concussions in the 2008-2009 academic year: mechanism, symptoms, and management.*  

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Meehan, WP, 3rd, & R Mannix.  
*Pediatric concussions in United States emergency departments in the years 2002 to 2006.*  

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Marar, M, et al.  
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*Second impact syndrome: a risk in any contact sport.*  
Physician and Sportsmedicine, 1995;23(6):p. 27.
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*Second impact syndrome.*  

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*A Murine Model of Multiple Mild Concussive Brain Injuries and the Effects of Recovery Time on Cognitive Outcome.*  
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*Sport-Related Concussion.*  

Shulz, MR, et al.  

Meehan, WP, 3rd, P d'Hemecourt, & RD Comstock.  
*High School Concussions in the 2008-2009 Academic Year: Mechanism, Symptoms, and Management.*  

McCrory, PR, & SF Berkovic.  
*Concussive convulsions. Incidence in sport and treatment recommendations.*  

McCrory, PR, & SF Berkovic.  
*Video analysis of acute motor and convulsive manifestations in sport-related concussion.*  

Meehan, WP, et al.  
*Computerized neurocognitive testing for the management of sport-related concussions.*  
Lovell, MR, et al, 
*Recovery from mild concussion in high school athletes.* 

Aubry, M, et al.  
*Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries.*  

McCrory, P, et al.  
*Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004.*  

Meehan, WP, 3rd.  
*Medical therapies for concussion.*  

Gronwall, D, & P Wrightson.  
*Cumulative effect of concussion.*  

Lau, B, et al.  
*Neurocognitive and symptom predictors of recovery in high school athletes.*  

Collins, MW, et al.  
*Cumulative effects of concussion in high school athletes.*  

Meehan, WP, 3rd, et al.  
*Increasing Recovery Time Between Injuries Improves Cognitive Outcome After Repetitive Mild Concussive Brain Injuries in Mice.*  

Daneshvar, DH, et al.  
*Helmets and mouth guards: the role of personal equipment in preventing sport-related concussions.*  
Mihalik, JP, et al.
*Collision type and player anticipation affect head impact severity among youth ice hockey players.*

Mihalik, JP, et al.
*Head Impact Biomechanics in Youth Hockey: Comparisons Across Playing Position, Event Types, and Impact Locations.*
The purpose of this presentation is to address sideline assessment of concussion using the SCAT3 assessment tool.

At Northeastern University we see a lot of Division 1 - Division 3 athletes in sports where concussions occur – especially...
soccer and hockey. It is important for us to have some sort of evidence-based approach to this assessment.

There are cases when it’s obvious the athlete is concussed—he doesn’t know where he is or what day it is—but that’s rare. Often the situation is much more subtle or complex. Sometimes an athlete may not report the concussion because they don’t want to be removed from play. Much more often, the athlete doesn’t even know they have a concussion. Studies have shown that most athletes who don’t report a concussion didn’t know it was a big deal. Or they may not notice the symptoms. We often hear situations in which athletes get hit in a Friday night game and it’s not until they go back to school on Monday that they realize all is not well. Another important point is that the concussed athlete may not have the cognitive ability to recognize there’s a problem—they’re not “with it” enough to realize they’re not “with it.”

This situation necessitated a standardized test that went beyond the standard “what’s the score?” and “what day is it?” questions.

As a result we saw the development of the first Sports Concussion Assessment Tool (SCAT) in 2005. That was revised in 2009 as SCAT2. We now have SCAT3 and the Child’s SCAT. The latter recognizes the need for a different test for younger athletes aged 5-12. SCAT3 is for athletes aged 13 and over.

SCAT3 offers evidence-supported tests to determine whether or not an athlete is concussed. The goal isn’t just to have a tool to use on the sideline after the injury but also something that will help us develop baseline scores before the injury. This standardized form helps us do things like measure the
athlete’s balance and cognition prior to an injury so we have something to measure against when we think there’s a possibility of a concussion.

Of course, the SCAT may not even be necessary if certain criteria are in place. For example, if the athlete scores less than a 15 on the **Glasgow Coma Scale** (Fig. 12.1).

![Glasgow coma scale (GCS)](image)

**Figure 12.1**

Additionally, if any of these signs are evident after an injury, the athlete should not be allowed to return to play:

- Any loss of consciousness
- Balance/motor incoordination
- Stumbling, slow movements
• Confusion/disorientation
• Responding inappropriately to questions
• Loss of memory
• Blank or vacant look
• Visible facial injury in combination with any of the above

But if an athlete makes it past this stage, we start the SCAT3. This is most often reserved for the athlete who isn’t obviously concussed according to the Glasgow Coma Scale or the above criteria.

The Maddocks Score (Fig. 12.2) evaluates cognition. It has excellent specificity (86-100%) but less sensitivity (32-75%). There is a variable false-positive rate but a very low false-negative rate. So in other words, it’s unlikely that we will have missed anyone with a concussion if they test without concern on the Maddocks Score.

The Maddocks Score is helpful as part of a larger assessment and is really designed specifically for the sideline, not for serial testing to establish a baseline.

The main difference between SCAT2 and SCAT 3 is the elimination of a combined score for all section. There is evidence
that individually the sections and their scores are helpful, but no good evidence for a total combined score out of 100. The SCAT3 is simply evaluated section by section.

The third section is **Symptom Evaluation** (Fig. 12.3). This involves having the student athletes themselves rank their symptoms. This can be very helpful for establishing a baseline during the preseason. Because as anyone who deals with concussed athletes knows, it’s easy to know where you stand when a concussed athlete who never gets headaches goes from zero on the headache score to four or even six,
and then goes back to zero again. But if the athlete regularly has headaches or one of the other symptoms—anxiety, say, or difficulty focusing—that makes it much more difficult to measure their concussion status after injury.

It’s important to note that the Symptom Evaluation portion of SCAT3 has variable sensitivity (64-89%) but very strong specificity (91-100%).

This graded Symptom Evaluation is the most commonly used concussion assessment simply because it’s so reliable. There are two ways of interpreting it: 1) It measures how many symptoms you have and your score is 22 minus those symptoms. The higher the score, the better shape you’re in. So if you register the maximum score of 22 you have zero symptoms. If you have a score of 10 that’s a much more serious problem. 2) The second way of interpreting this portion of the test is by assessing the severity of the symptoms. This is the test we tend to use the most in our office. There is a maximum possible score of 132 with a higher score meaning you have a more severe concussion. We look to see that score lower as the athlete gets better.

The next area we look at is true Cognitive Evaluation (Fig. 12.4). There are four scoring components to this. The first is the orientation to time. There are five questions about this: What month/date/day/year/time is it?

Then there’s word recall. On SCAT3 they give you four sets of words so the tester doesn’t have to make it up themselves on the spot – or remember them in the heat of the moment. We then move into lists of numbers of increasing length. Again the test gives the tester lists to choose from. Then we do months of the year in reverse order – December
through January which can be a challenge even if you’re not concussed.

These tests highlight why it’s important to have a baseline. There might be athletes who can’t recite the months of the year in reverse order when they’re not concussed. Some dyslexic athletes simply can’t do these kinds of tests – concussed or otherwise.
After we finish the remainder of the tests we return to these specific cognitive tests to test “delayed recall.”

If you look at the reliability of the standardized assessment of concussion (SAC), you’ll see it has been validated in numerous studies and has been shown to have a sensitivity of 80-94% and a specificity of 76-91%. When we talk about reliability we’re referring to a “change from baseline” – not just testing the athlete at a specific moment in time.

Studies show that if you’re looking at a 2-4 point drop in an overall SAC score then we can see a reliability somewhere between 42-71%. It’s by no means perfect but it’s certainly a very helpful tool.

What about the Physical Evaluation?

Because of the mechanism of concussion—a twisting type injury causing rapid acceleration and deceleration—we need to do a Neck Examination (Fig. 12.5). A Balance Examination (Fig. 12.6) is also important, and for this we use the standard Balance Error Scoring System, or BESS. This has been shown to be very reliable. But because it’s not easy

![Figure 12.5](image-url)

Neck Examination:

<table>
<thead>
<tr>
<th>Range of motion</th>
<th>Tenderness</th>
<th>Upper and lower limb sensation &amp; strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Findings:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 12.5

to do on both a hard and a soft surface in a sideline situation, as called for in the “true” BESS, we generally just do it on a hard surface. We don’t just look for errors when they’re doing these tests – we also look to see if they’re compensating by opening their eyes or readjusting in other ways. Then there’s the “tandem gait” test where we ask them to walk heel-to-toe down three meters of sports tape. The goal is to be able
to complete these tests within 14 seconds and then compare the results to baseline. The **Coordination Exam** (Fig. 12.7) involves the common finger-to-nose tests and if they can do that 5 times in less than 4 seconds they get 1 point.

The eighth and final section of SCAT3 as mentioned earlier is the “word recall,” or **SAC Delayed Recall** (Fig. 12.8).

SCAT3 involves eight sections of evidence-based standardized tests we can use to assess concussion. But we need to keep in mind SCAT3 is just a tool. Even the people who developed SCAT3 are very clear when they state right there on the form: “The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The
SCAt3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is ‘normal.’”

It’s important to understand that it can be a moving target and that we don’t always know what the symptoms are, which might change five minutes after the event, five hours after, and even five days after.

The most important point to make is that our overall goal is to keep our athletes safe.

In other words, if an athlete does just fine on any and all the tests but your opinion as a medical professional is that there is something wrong, then that is a trump card. There is nothing better than your clinical impression. That is still the gold standard.

I want to conclude by recognizing state laws on concussion. There are now only a couple of states that don’t have laws addressing this issue. The Massachusetts laws governing concussion came out in 2012. We should be mindful of this law which reads as follows:

*All students in extracurricular athletics must provide concussion, head, and spinal injury history*

*Any athlete showing signs or symptoms suggestive of concussion after a head injury must be removed from game or practice – not allowed to return that day, must be evaluated by a medical provider to return*
Must follow graduated return to play plan; must be completely symptom-free at rest prior to beginning.

Effective September 2013 - any healthcare provider clearing a concussed athlete must have documented Department-approved training in post-traumatic head injury assessment and management – CDC or other approved training.

A full audiovisual record of this presentation is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79303884
Suggested Readings

Guskiewicz KM, et al.

Yeates KO, et al.

Maddocks DL, et al.
*The assessment of orientation following concussion in athletes.*

Notebaert AJ, & KM Guskiewicz.
*Current trends in athletic training practice for concussion assessment and management.*

McCrea M.
*Standardized mental status testing of acute concussion.*

Broglio SP, SN Macciocchi, & Ferrara MS.
*Sensitivity of the concussion assessment battery.*

*Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete.*

Barr WB, & M McCrea.
*Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion.*

McCrea M.
*Standardized mental status testing on the sideline after sport-related concussion.*

*Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study.*
McLeod, TC Valovich, DH Perrin, KM Gusiewicz, et al.  
*Serial administration of clinical concussion assessments and learning effects in healthy young athletes.*  

McLeod TC Valovich, WB Barr, M McCrea, et al.  
*Psychometric and measurement properties of concussion assessment tools in youth sports.*  
J Athl Train 2006; 41:399–408.

Naunheim RS, D Matero, & R Fucetola.  
*Assessment of patients with mild concussion in the emergency department.*  

*Evaluation of the standardized assessment of concussion in a pediatric emergency department.*  
Pediatrics 2010; 126:688–95.
Preventing Running Injuries

Pierre d’Hemecourt, MD
Thomas W. Vorderer, DPM

Drs. d’Hemecourt and Vorderer presented on running injuries. Dr. d’Hemecourt focused on the relationship between gait analysis and running injuries, while Dr. Vorderer discussed the importance of good biomechanics to running injury prevention.

A full audiovisual record of these presentations is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79333585
Dr. Yen and physical therapists Michelina “Mickey” Cassella and Steve Clark presented on hip injuries in hockey. Dr. Yen introduced the topic with a description of anatomy and injury incidences and mechanism. This was followed by demonstrations of patient evaluations by PTs Cassella and Clark.

A full audiovisual record of these presentations is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79294387
Preventing Throwing Injuries

Donald S. Bae, MD
Benton E. Heyworth, MD
Craig Parsons, PT

Dr. Donald Bae, Dr. Benton Heyworth, and Craig Parsons, PT, presented on injuries in throwing athletes. Dr. Bae introduced the topic with a discussion on shoulder injuries followed by Dr. Heyworth’s discussion on elbow injuries. This was followed by a detailed description by Craig Parsons on in-season and off-season exercise programs to prevent shoulder injuries in young athletes.

A full audiovisual record of these presentations is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79294387
Preventing Dance Injuries

Bridget J. Quinn, MD
Andrea Stracciolini, MD
Ellen Geminiani, MD
Ruth Solomon, BA, CMA

Drs. Quinn, Stracciolini, and Geminiani and Professor Solomon presented on dance injuries. Dr. Quinn introduced the topic following which Dr. Stracciolini addressed the relationship between growth and dance injuries. Dr. Geminiani focused on readiness for dancing on pointe while Professor Solomon described the importance of teaching proper technique to preventing injuries in dance.

A full audiovisual record of these presentations is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79305139

Professor Solomon’s presentation follows.
Technique class should be the first stop in injury prevention, as that is where young dancers develop the habits that either promote or undermine good health. This means that teachers should make use of anatomically sound concepts in the training of young dancers. Unfortunately, in actual practice there are usually discrepancies between what is taught and the biomechanical reality of how the body properly functions. This results from the fact that dance teachers traditionally use the same language, images, and technical corrections they experienced as a student; hence, misconceptions readily become part of the ritual of dance training and are passed on from generation to generation. Until recently there has been little published research to offset these misconceptions. It is important for health practitioners to understand this, as their advice may be counteracted in the daily routine of the dancer.
The primary example of these “misconceptions” is ballet teachers’ demand for 180° of turnout (external rotation). Research has shown that dancers can only achieve at most 60% of this at the hip; thus, they utilize various strategies to fulfill the requirement, all of which are potentially injurious. As dancers are thin and creative at disguising their accommodations you have to cultivate an eye to seeing the resulting mal-alignments.

When looking at a dancer in clinic, observe from the side (Fig. 13.1). Everything begins with a centered pelvis (centering has the implication of something in motional flow, which changes depending on the movement). From 1st position ask to see passé (Fig. 13.2). Anterior pelvic tilt may result in “snapping hip,” iliopsoas tendinitis, labral tears, etc. It inhibits correct placement of the femur for développé, rond de jambe, and most movements required in dance. Insertion of the femur in the hip socket is unique to each dancer, and problems may result from improper seating in the acetabular. Posterior pelvic tilt (Fig. 13.3) may result in: forward head thrust, kyphosis, contracted rectus femoris and iliopsoas. As antidotes to these problems utilize psoas strengthening and stretching work.

Another tradition that causes unnecessary problems for dancers stems from the fact that they are expected to “warm up” before class. Some—indeed, most—mistakenly do this by stretching before they have enhanced blood flow to the muscles through some form of vigorous movement. Additionally, due to lack of or misguided instruction, they often use stretching techniques that are potentially injurious. One simple favor medical personnel involved in the prevention of dance injuries can do for their clients is to inquire about their warm up technique and recommend appropriate alterations.
Essentially, each dancer is responsible for him or herself. The medical advisor will not be with that dancer throughout their career. The more a dancer knows about how to work efficiently and biomechanically, the longer they will last. It is our responsibility to teach for the long run. The healthcare practitioner should provide the impetus, techniques, and information in a way the dancer can understand, and ultimately take on that responsibility.

Keep dancers dancing longer.
Suggested Readings


Philippon MJ. *Hip Arthroscopy – from diagnosis to patient outcome.* Grand Rounds presented on September 29, 2011, Massachusetts General Hospital, Boston, MA


Preventing The Female Athlete Triad

Kathryn E. Ackerman, MD, MPH
Catherine M. Gordon, MDMsc
Jan P. Hangen, MS, RD, LDN

Drs. Quinn, Stracciolini, and Geminiani and Professor Solomon presented on the Female Athlete Triad. Dr. Ackerman introduced the topic following which Dr. Gordon addressed the most current information on this issue. This was followed by a Q&A session with all three presenters.

A full audiovisual record of this presentation (minus the Q&A session) is available courtesy of Boston Children’s Hospital Visual Services at: http://vimeopro.com/anchorline/micheli/video/79333584

Dr. Gordon’s presentation follows.
The Female Athlete Triad refers to the concept of low energy availability. Patients do not have to meet the criteria for an eating disorder – it can involve insufficient calorie intake relative to how much exercise the athlete is engaging in as part of their training regimen. The net energy deficit results in changes in hormones, which may lead to a change in the menstrual cycle, and in particular, menstrual irregularity, and ultimately, can affect bone health in a deleterious way.

The following text is a summary of the oral presentation made by Dr. Gordon at the First Annual Micheli Lecture.

The Female Athlete Triad refers to the concept of low energy availability. Patients do not have to meet the criteria for an eating disorder – it can involve insufficient calorie intake relative to how much exercise the athlete is engaging in as part of their training regimen. The net energy deficit results in changes in hormones, which may lead to a change in the menstrual cycle, and in particular, menstrual irregularity, and ultimately, can affect bone health in a deleterious way.
When considering the consequences of the Female Athlete Triad, one of the key points to recognize is that over half of the skeleton is laid down during the teenage years (Fig. 13.4).

![Bone Mass vs Age Chart]

This discussion focuses on the young female athlete, but it is important to make the point that we are seeing more and more boys with eating concerns and weight concerns among young women, and I am concerned that in the not too distant future, we will start seeing more males with a lower peak bone mass and problems with regard to bone health.

Most of us see boys and girls and use growth charts to assess their development. It is important to use these charts to assess bone health, too – we need to recognize that problems with gains in weight and height may also be affecting bone accrual.

There are many determinants of bone mass accrual. These may be divided into internal and external factors.
At this point in time, it is not feasible to genotype every patient, so that reinforces the importance to consider earlier densitometry assessments (i.e., measurements of bone density) on patients, especially if there is a red flag in the history, such as a relative who has osteoporosis/osteopenia.

Obviously, we cannot perform a bone biopsy on every patient we see, and yet, because this is such an important issue, one of the goals for us in the pediatric bone health field is to find a non-invasive way to assess bone health in children.

Because female athletes are at higher risk for early osteoporosis, I have been on a personal campaign with other doctors to establish the female menstrual cycle a “vital sign.” In the same way that we measure blood pressure and heart rate, we should be asking girls if they are having regular menstrual periods. If they say “no,” that should be a red flag to clinicians that something may be going on with their nutrition. Or they may carry another diagnosis of concern such as polycystic ovary syndrome that it is important to know about.

Delayed puberty is more often a problem in girls who participate in sports where leanness is considered an asset – dance, figure skating, gymnastics, etc.
Primary amenorrhea is defined as no menses by the age of 16 years, but I think we need to be concerned by age 15. Nine or more periods per year is normal and there should only be a “grace period” of one year for irregular periods. After that, girls should follow a regular 28-45 day cycle.

We see a lot of athletes in our practice and are trying to catch them before things deteriorate to the point where the symptoms become as serious as they are in the patient shown in Figure 13.5. This adolescent girl meets the DSM-IV criteria for anorexia nervosa. This condition may include several endocrine abnormalities.

It is important to keep in mind that Vitamin D deficiency appears to be less common in

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**Hormonal Alterations In Anorexia Nervosa**

- Growth hormone resistance
- High GH, but low IGF-I
- Low estradiol
- Low androgens (including DHEAS and testosterone)
- High cortisol
- Vitamin D deficiency (rarely) (typically, normal 25OHD + PTH)
adolescents with eating disorders because these patients are very compliant with taking vitamins and supplements. Thus, as clinicians, we have to consider carefully other reasons for bone loss.

What is the appropriate work-up we need to pursue in a young adolescent who has pubertal delay or amenorrhea? Getting baseline measurements of bone density by dual-energy x-ray absorptiometry can be very helpful. We also order a left hand x-ray to evaluate whether an athletes’ bone development is in synch with his/her chronological age. It us also important to cast a broad net. There is a battery of general tests I order in all of these patients to rule out secondary causes of bone loss beyond overexercise and/or an eating disorder:

- Bone age x-ray (to calculate target height and assess for delay)
- Chem-10 panel
- CBC
- Free T4 and TSH
- FSH
- Prolactin
- 25OHD
- Cranial MRI (select cases)

What is the course of action when one is concerned about an athlete who has an eating disorder or issues relating to an energy deficit – calorie input deficit and over-expenditure of calories?

It is important to assemble a multi-disciplinary team. We have great teams both here at Boston Children’s Hospital and at Hasbro Hospital in Providence, Rhode Island where I am now working. Usually the team is led by a physician or nurse...
practitioner. He/she is generally assisted by a nutritionist or dietician who sees these patients as often as every weekly. A therapist is key to helping understand why this young person is resisting food intake. And an orthopedist is vital when these patients get injured, and for that same reason, so is a physical therapist. It is also important that there be regular communication with coaches and teachers.

It should be emphasized that the considerable benefits of weight-bearing exercise on bone health are lost if a young woman becomes amenorrheic.

When should the athlete get baseline DXA scans? Recommendations vary among experts. My recommendation is six months after amenorrhea is detected as is helpful to know where a patient’s starting point is with respect to bone density. I was part of an International Society of Clinical Densitometry conference back in 2007 at which time guidelines were established for what constituted an “abnormal” bone density by DXA. The consensus was that a bone mineral density (BMD) Z-score of less than -2.0 was a cause for concern. The American College of Sport’s Medicine’s recommendation is to red-flag a Z-score of -1.0 or less, which I think is more appropriate for young athletes. The literature shows that it is at a BMD Z-score of -1.0 that an increased fracture risk arises for a child or adolescent.

DXA gives us a measure of the axial skeleton and on the horizon, we are looking at scans obtained by peripheral quantitative computed tomography (pQCT) to provide accurate measures of peripheral skeleton. This is still in the research phase, but studies are being done in other countries that show this is an effective tool. We are still trying to figure out the billing issues. pQCT is also helpful for assessing the trabecular and cortical components of the skeleton.
Remembering that 80% of our bones are cortical and 20% metabolically active trabecular bone, and it can be very helpful to track these separate bone compartments in a patient, as is possible using pQCT (Fig. 13.6).

Adolescence is a very important time to build bone health, and an overarching goal is to maintain skeletal health for the rest of our lives. That means that if a young woman’s hormones are imbalance because they are not eating enough, then their bones are going to suffer. What we try to emphasize to young athletes—who tend not to heed warnings about endocrine health and topics such as osteoporosis in later life—is that the problems that result from this situation make them unable to play. That warning has much more impact than theoretical concerns.
Suggested Readings

**Effects of oral dehydroepiandrosterone on bone density in young women with anorexia nervosa: a randomized trial.**  

Loud KJ, LJ Micheli, SK Bristol, SB Austin, & CM Gordon.  
**Family history predicts stress fracture in active female adolescents.**  

Golden NH, & JL Carlson.  
**The pathophysiology of amenorrhea in the adolescent.**  

Gordon CM.  
**Functional hypothalamic amenorrhea.**  

Misra M, & A Klibanski.  
**Anorexia, obesity and bone metabolism.**  