**Objective**

To develop an objective and reliable method for measuring surface hardness for grounds in the Australian Football League (AFL) that may be able to assess ground risk for Anterior Cruciate Ligament (ACL) injury.

**Method**

Nine penetrometers (Gill Engineering, Melbourne), as seen in figure 2, were obtained for the major AFL venues around Australia. Readings were made on the morning of games during the 1997 and 1998 seasons. Penetrometer readings were measured in centimetres as an average of three drops at twenty different locations spread evenly around the playing field (figure 3). Daily weather variables (rainfall and evaporation) were obtained by the Bureau of Meteorology at central locations in each city studied.

**Discussion**

Previous study has found that 365-day rainfall and 28-day evaporation are significant risk factors for ACL injury in Australian Football (Orchard et al., 1999). This study has found that 365-day evaporation and 14-day rainfall correlate highly (p<0.0001) with ground hardness as measured by the penetrometer. These two studies show an association between ground hardness and risk of ACL injury. This may be either because hardness is a direct risk factor for injury or because it correlates highly with a confounding factor (such as traction) which is a risk for injury. As the weather variables that predict ACL risk and ground hardness are not exactly the same, it is likely that other surface-related factors are implicated in the risk of ACL injury.

Hardness of natural turf is mainly controlled by moisture content whereas traction is related more to grass cover (Baker, 1991). There is a need to develop easy and portable methods for measurement of ground conditions such as hardness and traction. If hardness and/or traction have a direct relationship with ACL risk, then grounds can be prepared differently to lower this risk for football games played on natural grass.

The Penetrometer is an internationally used instrument to measure the hardness of horse racetracks which is objective, reliable and correlates with race time (Neylan et al., 1998). It measures depth of penetration of a shaft into the turf after dropping a weight from a set height. Other devices, such as the Clegg hammer, measure hardness by deceleration of a weight (Clegg, 1976) but are more expensive than Penetrometers (US$2500 versus US$600).

**Results**

There were 168 matches (at 9 venues in 8 cities) where Penetrometer readings were taken and preceding rainfall and evaporation measures were available. The average Penetrometer reading was 4.7 cm (range 2.9-6.3). A higher reading (greater penetration of the weight) indicates a softer playing surface. Composite rainfall and evaporation variables were created (measuring the totals for the previous 7, 14, 19, 30 and 365 days). A multiple regression model was created with the Penetrometer reading as the dependent variable. Using composite rainfall and evaporation variables a significant (P<0.0001) regression equation was developed:

\[
\text{Penetrometer reading (cm) = 5.677 + 0.000742(365-day evaporation) + 0.000322(14-day rainfall)}
\]

In this equation the t values with 165 degrees of freedom were -7.493 for 365-day evaporation (P<0.0001) and 3.763 for 14-day rainfall (P=0.0002).

An alternative equation using a rainfall deficit (evaporation - rainfall) composite variable was also significant (P<0.0001):

\[
\text{Penetrometer reading (cm) = 5.639 + 0.000637(365-day evaporation) - 0.000343(14-day evaporation - rainfall)}
\]

**References**


