THE LOADING OF THE MUSCULO-SKELETAL SYSTEM IN TENNIS
OR: WHY DO PEOPLE GET INJURED IN TENNIS
OR: IS TENNIS REALLY HEALTHY
OR: WHAT CAN WE DO TO REDUCE INJURIES IN TENNIS.

Benno M. Nigg,
Professor of Biomechanics
Faculties of Physical Education,
Medicine and Engineering,
University of Calgary
Calgary,
Canada

Tennis has undergone a rapid development in the last twenty to thirty years. From a sport which in may countries was only open to a small number of privileged classes tennis developed into a popular sport for everyone. Due to covered courts the summer sport changed to a twelve-month sport, even in regions with very harsh winters. The former informal leisure-time activity changed for many players to competitive involvement with training, competition and tournaments demanding advanced levels of fitness and preparation. The game, once only played on two types of surfaces (clay or grass) is now played on a variety of other surfaces such as asphalt, carpet, synthetic surfaces, sliding synthetic surfaces (slide or fluid), artificial grass with and without sand and turf. Synthetic materials were introduced for rackets and their size and shape were changed. Tennis really has changed drastically since the 1950's.

However, there was another change connected with the fascinating sport tennis: the number and the kind of TENNIS INJURIES. Parallel to the explosive development in surface, racket and other technical aspects, problems connected with the health of tennis players became more frequent. The number of tennis players who visited the physician because of tennis injury increased. It is difficult to decide whether this increase in tennis injuries really increased or whether this increase in tennis injuries is only a consequence of the increased number of players while the relative percentage of tennis injuries remained constant. This aspect may be interesting but it is not relevant in this context. The only relevant fact is that many (too many) tennis players are affected with tennis injuries and the question to be answered is how can such tennis injuries be reduced or avoided. In order to be able to answer this question one must understand why and where tennis players get injured: one has to understand the factors responsible for load and overload in tennis. If we know these factors we can develop a strategy to avoid such overloading situations which are the origin and cause of these injuries. However, first one has to know the reasons for these injuries. The purpose of the following explanations is therefore to try to understand some of these factors which are responsible for tennis injuries. Every connoisseur of tennis is anxious to play his or her sport as long as possible without any encumbrance and without acute or chronic injuries. We would be pleased if these explanations could help one or the other tennis player to avoid tennis injuries and if generally the rate of tennis injuries could be reduced.

In the first step we have to analyse systematically the factors responsible for forces acting on in the body of a tennis player. There are two groups of factors, which are important. On one side there is movement. It is evident that the forces in a knee joint for instance are different for a landing after a one-foot jump or a landing after a jump from the second floor of a house since the movement is different. It is also obvious that the forces in an achilles tendon are different during the landing on concrete or the landing on a foam cushion. Again, the movement is different. One can summarize these factors which are connected with the movement under the expression "DYNAMIC FACTORS". They describe how a tennis player executes the various movements. On the other side there are factors like racket, surface, shoe and temperature which, may also have an influence on the frequency of injuries. To play barefoot on asphalt or with tennis shoes on clay may produce different forces in joints, tendons, muscles, ligaments or skin. Let us call these factors " BOUNDARY CONDITIONS". Dynamic factors (movement) and boundary conditions are inter-connected. We can illustrate that with the example of a back-hand stroke on clay and the back-hand stroke for the same player on an asphalt court. The position of the body at first contact with the ground for the stroke is totally different. On clay courts, or more generally on courts with low friction where sliding is possible, the player places the foot relatively flat on the ground which enables him to slide. The same person places the foot at an angle landing clearly with the heel if anticipating that on a surface sliding is not possible. However, not only the foot position is different, positioning of the lower leg and the knee angle and even the position of the racket are different on the two surfaces. On a sliding surface the person takes a very early position in which the stroke is executed. On a not sliding surface the foot cannot move and therefore the lower extremity and lower part of the body constantly change their position relative to the foot during the last contact and during the stroke. It is obvious that the forces in these two examples act differently and it is evident that certain boundary conditions may produce higher loading of the human body and that they may be responsible for tennis injuries.

The following explanations will concentrate on various boundary conditions and discuss how they may affect load and overload on the body of a tennis player with the main emphasis on the tennis injuries in the lower extremities. Basically, there are different approaches possible. On the other hand one could try to quantify (measure) these forces. However, this approach is very difficult and in certain cases not even possible. On the other hand one could try to study tennis players which are or were injured. We decided to use this second approach and performed three studies. Procedure and results of these studies will be discussed in the following. The first two projects were preformed at the Technical University in Zurich (ETH Zurich) together with my students (T. Hasler, U. Spiess and U. Hasenfratz) , my co-workers (E. Unold and J. Cenoth) and our medical consultants (U. Froehlicher and B. Segesser). The third project was performed at the University of Calgary with my co-workers (S. Luethi and M. Hawes) and supported by the Nike Shoe Corporation. The first project (1979) was based on a questionnaire including 115 tennis players. The second project back in 1980 was based on the results of the first study using a questionnaire with 1018 tennis players over a period of an outdoor (summer) and an indoor (winter) season. Both were retrospective studies. That means all answers for the questionnaire were given a certain time period after the actual event (the actual tennis injury). In both studies the tennis players answered questions with respect to material, injuries, surface, shoe, etc., without the help of a specialist. The third project (1983) was a prospective study which, was highly controlled. We started with 230 initially healthy tennis players and followed them closely throughout the period of about 2 – 3 months. Occurring injuries were immediately diagnosed by a physician. The details of the procedures will be reported in scientific journals. Here only the (for a tennis player) more interesting results were reported. They are discussed in two groups, the first group including the two retrospective studies and the second group including the prospective study.

Results of the retrospective study:

One of the most surprising and interesting results of this retrospective study was the fact that 52.6% of all the cases analysed indicated pain and/or injuries. This result was the same for the first study with the smaller and the second study with the larger sample of subjects. This means that one out of two tennis players most likely has a tennis injury during one season (6 month) of playing. A sub-division of pain and injury into stroke-pain (pain as a result of the tennis stroke mainly located in the upper extremities) and locomotion pain (pain mainly due to the moving and running on the surface) shows that locomotion pain was more frequent than stroke pain. (3:2). Figure 1 illustrates the number of cases with pain located in the lower extremities, back and groin. The upper extremity pain numbers were about 200 for the wrist, about 280 for the elbow and about 250 for the shoulder. It is obvious that back pain, knee pain and ankle joint pain are the most frequent pain occurrences. (Note that a number of subjects had multiple pain).

Concentrating on the lower extremities we try to find out where the origin or the cause of these injuries lies. This aspect of the project showed a result, which again was very interesting. After eliminating all the cases where it was possible to find an "outside" origin of pain ("outside" means that this origin was not connected with the surface) an analysis was done that computed the percentage of cases with pain on the different tennis surfaces. The surfaces used in this study were, (1) sand or clay, (2) a synthetic sand which is a synthetic surface with a synthetic sand on top of it which allows rotation and sliding movements, (3) a synthetic surface, (4) asphalt, (5) a felt carpet type of surface commonly used in Europe and finally, (6) a synthetic grill, which is sometimes placed on top of concrete surfaces of ice rinks for the summer time. The results of this analysis are summarized and illustrated in figure 2. This figure shows a very interesting result. There are two surfaces, sand or clay on one side and synthetic sand or slide on the other side, which have relatively small injury frequencies (less than 3%) and a group of four surfaces which have higher (between 10 and 20%) injury frequencies. Statistically the results for the first two surfaces, clay and slide, are different from the other four surfaces. This result illustrates that obviously the surface is instrumental in the occurrence of pain and we now have to try to understand why this is the case. In order to do so we quantified the influence of different "outside" factors like the numbers of hours played on a surface, the social structure and other aspects in order to see whether they have an influence on the occurrence. The result was negative. As a second step we went to the mechanical characteristics of the different surfaces. There are mainly two aspects, which we had to look at. One aspect was the vertical resilience and the other aspect was the frictional behaviour. The vertical resilience did not show any significant influence on the occurrence of the injuries in tennis. However, the frictional behaviour was the factor, which came out as the most important with respect to injuries in tennis. The two surfaces with the lowest percentage of cases with pain, the surface sand/clay and the surface synthetic sand/slide were the surfaces that had a much lower friction coefficient and allowed a sliding during the preparation for the stroke. The other surfaces did not allow that. One may argue that this result is influenced by the different players playing on the different surfaces. However we did one study in order to check this aspect and the results are illustrated in Table 1. It shows the relative frequency of pain for a specific surface compared to clay for the same group of subjects playing for 6 months on the specific surface and 6 months on clay. The results show, that in every case clay, always had less injury than the other surfaces. This means that the previous result was confirmed. "Sliding" surfaces (surfaces which allow sliding) are most likely to have less tennis injuries.

The conclusion based on these results is quite clear. From point of view of surface the most important aspect is the frictional component. Surfaces, which allow sliding, are most likely to have less injury than surfaces, which don't allow sliding. In other words whenever somebody wants to build a tennis court and has in mind to look at the injury aspect, the aspect of sliding is the most important one. Statistically we couldn't find a difference for the different resiliency of the surfaces. We would therefore speculate that the resilience of tennis surface is not that important from an injury point of view. However, it may be important from a comfort point of view.

There are many different surfaces currently on the market that allow sliding. The most conventional one is clay type surface or the sand surface (Aschenplatz) in Europe. More modern surfaces are the "slide" surface which is a synthetic surface which has on top a loose granulate of the same material. This surface allows sliding in a similar way as clay or sand courts do. The amount of sliding can be tuned, with the size and the form of, the synthetic granulate. Another possible surface construction that allows sliding is a turf system filled with sand. This sand in the turf system allows the sliding too and again is expected to reduce the number of injuries due to tennis activities. (Note that this surface can also be used for other sports other than tennis, for instance field hockey, football and soccer.) One hears quite often that it is possible to slide on surfaces like asphalt or synthetic surfaces or generally on surfaces that don't have an additional sand or granulate on top. Our experiments and our investigations did not show such sliding except on very rare occasions. The average sliding distance during playing on a concrete surface is close to 0 cms or 0 inches. The construction of the shoe does not seem to be able to solve the sliding problems. This means that for horizontal sliding possibilities the surface has to be constructed in a way that the upper part has loose particles, which allow sliding. It is expected that the use of such surfaces is connected with a drastic reduce of tennis injuries. However, there is another important aspect, which is connected with the rotational resistance. We have data which, show that the rotational resistance (torque) can easily be reduced by 50% due to the sole construction. However, we don't have any data to show whether this is connected with a reduction of injuries. We speculate that a shoe with little resistance would reduce the injury frequency compared to a shoe with higher rotational resistance. However, these are speculations compared to the hard facts of the results with respect to transitional friction. As mentioned before, the aspect of cushioning the tennis surface is not so much an aspect of reduction of forces and therefore reduction of tennis injury but much more an aspect of comfort. One aspect of this result, is in agreement with results we have based on our studies on tennis shoes and running shoes, where the subjects adapt relatively fast to the different cushioning systems and try to level their forces to a certain value (an aspect which is discussed in my new book "Biomechanics of Running Shoes").

Results of the prospective study.

As mentioned before, the prospective study was a study where we started with healthy subjects, let them play tennis, waited and assessed all the injuries that occurred during their tennis activity. It is obvious that in a short period of about 2-3 months the injuries or discomfort reported is mainly connected with slight pain and discomfort such as blisters, arch pain and so on. However, it is still interesting that 40% of all subjects involved in that study reported pain or discomfort. This high number of pain reported is certainly surprising or even alarming. Most of the pain reported was in the lower extremities and there concentrated on the foot. This was certainly connected with the fact that all the subjects received new tennis shoes at the beginning of the study (randomly we distributed two types of tennis shoes currently on the market). One shoe was a softer shoe and the other a bit stiffer. An interesting result of this study was that the subjects wearing the stiffer shoe had a higher percentage of cases with injuries and pain than the subjects with the softer shoe. The percentage of injury with the stiffer shoe was 47.1% and for the softer shoe 32.6%. This result illustrates that it is obvious that a shoe can influence the frequency of occurrence of pain, discomfort and/or injury. We certainly have expected such a result however, we didn't have the numbers to prove that. These results of this prospective study are proof that the shoe is one factor which is important in lower extremity injuries in tennis. There are two further points that should be discussed in this content. On one side, the different shoes had different locations where the subjects frequently had problems. The stiffer shoe had, for instance, a dominant part of all the toe, ankle and knee problems. The softer shoe had the dominant part of the arch problems and also slightly more calf problems. The shoe therefore, may be responsible for a typical type of problem and by changing the shoe, even not understanding cause and result, these problems may disappear. The second aspect which is interesting is the fact that the movement done in these may also be connected with some pain and injuries. The supinatory movement or the side rolling of the foot during side shuffling was different for the two shoes. In addition it was also different for the subjects with pain. Subjects with pain wearing the stiffer shoe had generally less supination (sidewards movement) than the subjects with the same shoe with no pain. While subjects wearing shoe 1 (the softer shoe) and having pain had generally more supination than the subjects wearing the same shoe and not having pain. This result leads us to the conclusion that the shoes have to be constructed not for a minimal pronation or supination but for an optimal range of pronation and supination. A shoe that is toe stiff may create different problems but may create problems. This knowledge is now used in construction of tennis shoes.

Conclusion

The results of these retrospective and prospective studies show that there are different factors which, may influence load and injuries in tennis. Two factors are clearly connected with the frequency of occurrence of locomotion injuries, the surface and the shoe. In the case of the surface, the solution seems to be clear. Surfaces that allow sliding are expected to have about 75% less locomotion injuries, than surfaces which do not allow sliding. Since "sliding" surfaces which allow a 24-hour per day tennis activity are now on the market a change to these sliding systems is expected to reduce the frequency of locomotion injuries in tennis. The situation for the shoes is not that clear. Further research is needed in this field and is currently underway.

However, the fact that the surface has such a dominant influence in the occurrence of locomotion, pain and injuries, leads us to the conclusion that this aspect should certainly be considered in the construction of tennis courts for the future.

Table 1 Frequency of injuries on several surfaces. S1 divided by the frequency of injuries on Sand/Clay S2.

Surface 1	Surface 2	Relation S1 : S2
Synthetic	Clay	1.8
Asphalt	Clay	1.7
Carpet	Clay	1.5
Turf	Clay	1.4

PERCENTAGE OF
CASES WITH PAIN

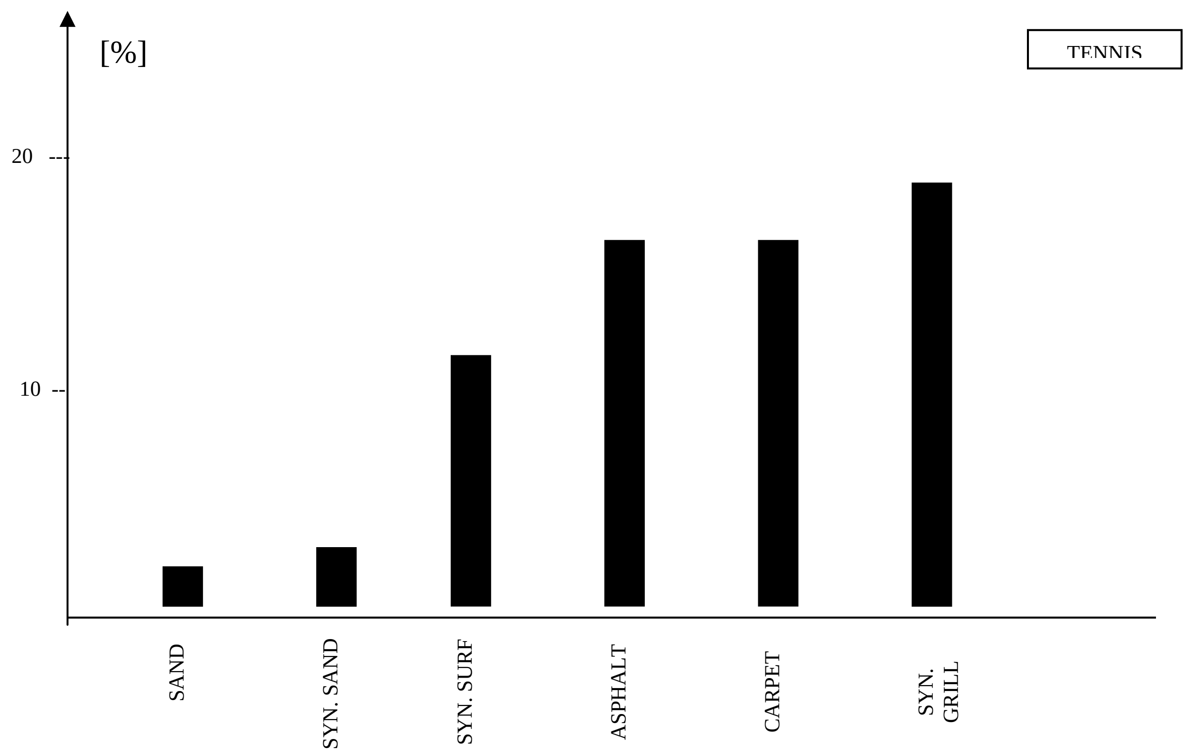

Fig. 2 Relative percentage of reported pain on different surfaces after eliminating pain due to other influences.

(1) Sand/Clay

(2) Synthetic surface with a loose granulate on top

(3) Synthetic surface

(4) Asphalt and concrete

(5) Felt carpet (on asphalt)

(6) Synthetic grill (on concrete)

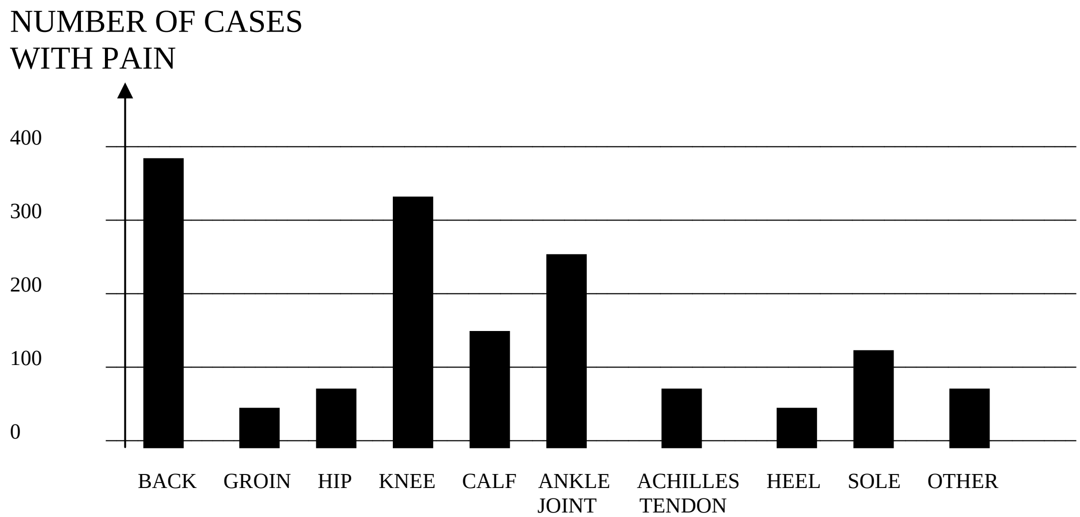

Fig. 1 Absolute number of reported pain in the lower extremities, back and groin in a retrospective study with more than 2000 cases.