FOOT LOADING ON FUNDAMENTAL MOVEMENTS IN FOOTBALL

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INTRODUCTION

Movements of football (soccer) players consist of several complex motions and interactions. Foot loading is one of the most important factors in the analysis of the interaction of football motion with equipment and shoe design in football (Bartlett et al., 1995, Hennig et al., 1996, Milani et al., 1995). It is also considered that the loading of the foot is related to overload type injuries in football. Therefore, it is important to analyze the loading of the foot for the improvement of skills and design of shoes in football (Eils et al., 2001).

The purpose of this study was to clarify the characteristics of the foot pressure distribution on the fundamental movements in football using an insole pressure distribution measurement system (F-scan system; Nitta Inc.). Moreover, we developed a biomechanical foot skeletal model using the finite element method and analyzed the stiffness of the foot complex using the oblique impact simulation.

METHODS

Six male university football players were chosen as the subjects in this study. The playing positions of the subjects were two goalkeepers (GK), two defenders (DF) and two forwards (FW). The F-SCAN system (Nitta Inc.) was used to collect plantar pressure information (Figure 1). All subjects were fitted with new football shoes (the typical 12-studs type) and the experiment was performed on an athletic field. Six football specific movements were performed: forward sprint at maximum speed, running backwards at maximum speed, side step, dive, turn and jump. The jump, turn, back step and side step all appear with high frequency in football, while diving is a specific movement of the goal keeper. The pressure scale of the foot scan system was set from 0 to 300 kPa, and was displayed as pressure contours in thirteen divisions. The data of the contact phase in this study was taken 3 ms after foot landing (Figure 2).

Pressure distribution and peak pressures were extracted for twelve areas such as the hallux (a-1), second and third toe (a-2), lateral toes (a-3), medial (b-1), central (b-2), lateral forefoot (b-3), medial (c-1), central (c-2), lateral mid-foot (c-3), medial (d-1), central (d-2) and lateral heel (d-3) (Figure 3).

The basic shape of the finite element lower extremity skeletal model was described using a commercial lower extremity skeletal model for computer graphics and anatomical data. The solid model was defined after simplifying the commercial model (Figure 4). The axis system of the model is chosen such that, with respect to the foot, the X-axis is horizontal and in the external-internal direction, the Y-axis is vertical along the tibia pointing in the upward direction and the Z-axis completes the right-handed rectangular coordinate system.

The hard tissue parts of this foot model consisted of 23 bone models such as the calcaneus, metatarsal, etc., and the soft tissue parts that consisted of 15 joint models such as the talocalcanean (subtalar) joint, calcaneocuboid joint, etc. The meniscus was included in the tibia model. The eight ligaments of the foot joint and the four ligaments of the knee joint (ACL, PCL, etc.) were also defined. The other ligaments and retinacula were not geometrically represented, consequently, the stiffness of the soft tissue parts were estimated including the function of the other ligaments and retinacula.

The finite element meshes were made from the solid model using a commercial pre-post processor (MSC.Patran), and the linear static analysis was solved using an implicit FEM code (MSC.Nastran). The dynamic transient analysis was performed using an explicit FEM code (MSC.Dytran). As material properties, the Young modulus of the hard tissue was 15 GPa and the Poisson ratio was 0.3 (Furusu et al., 1999). An isotropic linear viscoelastic shear model was used in the soft tissue. The Young modulus of the soft tissue was 1.5 GPa, the Poisson ratio was 0.4 and the short-time shear modulus was 536 MPa. The initial vertical velocity at impact was –1.0 m/s.

For comparing the lateral side stiffness of the foot complex, oblique angles were defined as 0.26 rad. rotated in the inversion direction (outside impact) and –0.26 rad. rotated to that (inside impact).

Figure 1: An insole pressure distribution measurement system (F-scan system; Nitta Inc.).
RESULTS AND DISCUSSION

A typical foot pressure distribution of the contact phase and the maximum pressure phase during a sprint are shown in Figure 5. In the contact phase, the main loading area was b-1, and the maximum value was 326 kPa. The maximum pressure phase showed a similar pressure distribution with a maximum pressure of 595 kPa. There was almost no load in the d area. The distributions were very similar for all subjects studied and thus average pressures were calculated. In the case of the forward sprint, the highest average contact pressure occurred at b-1, with a value of 197 kPa in the contact phase. The value of b-1 was also the highest in the maximum pressure phase, which was 379 kPa. Again, the d area at the heel showed very small pressures.

Figure 5: An example of distribution of pressure in sprint, (a) experimental data and (b) averages for six male soccer players.

The foot pressure distribution for contact and maximum pressure phases in the side step are shown in Figure 6. In comparison to the sprint, there were significant differences between some of the subjects. In the contact phase on the forefoot, they were divided into two types. In the first (Type A), the d area around the heel becomes the main load area (with the largest load on d-1). In the second (Type B) b-1 and a-1 under the joints of the toes become the main load areas.

In the rear foot, the main loading area was b-3. In the maximum pressure phase, both the forefoot and rear foot showed a large load at a-1 and b-1. The value of maximum loading of the rear foot is larger than that of the forefoot and the maximum difference was 426 kPa.

In the contact phase of the forefoot in the side step, the maximum average peak pressure was observed in d-1 in the heel.
as 173 kPa. In the maximum pressure phase of the forefoot in the side step, the maximum average peak pressure of 412 kPa was observed in b-1 (under the joints of the toes) and the second highest value of 305 kPa was in a-1. In the contact phase of the rear foot in the side step, the maximum average peak pressure of 119 kPa was observed in b-3, i.e. towards the outside of the foot (Figure 6). Especially, the wide area consisting of a-1, a-2, a-3, b-1, b-2, and b-3 indicated over 48 kPa. The average peak pressure in b-1 was 286 kPa and in a-1 was 229 kPa (Figure 6).

![Type A Type B](image)

(a) contact phase       maximum pressure phase

(b) contact phase       maximum pressure phase

**Figure 6:** An example of distribution of pressure in forefoot in side step, (a) experimental data and (b) averages for six male soccer players.

The foot pressure distribution of the contact and maximum pressure phase in turning for the inside foot is shown in Figure 8. For the inside foot, the main loading area was b-1 with a maximum value of loading of 654 kPa. For the outside foot, the main loading area was b-3, i.e. towards the outside of the foot. In the maximum pressure phase, the main loading areas were distributed across the inside of the foot and under the toes (b-1, b-2 and a-1).

In the contact phase of the inside foot in the turn, the maximum average peak pressure was again observed in b-1 as 169 kPa (Figure 8). The peak pressure value of other areas was under 64 kPa. In the maximum pressure phase of the inside foot, the maximum average peak pressure was observed in b-1 as 358 kPa. The b-1 indicated high values in both phases, the similar tendency was observed in diving and sprint.

In the contact phase of the outside foot during a turn, the maximum average peak pressure was observed in d-1 as 168 kPa. In the maximum pressure phase of the outside foot, the high average peak pressure was observed in a, b and c areas, and that of d areas indicated small values.

![Figure 7](image)

(a) contact phase       maximum pressure phase

(b) contact phase       maximum pressure phase

**Figure 7:** Average load in contact phase (a) and maximum pressure phase (b) in rear foot in side step for six male soccer players.

In the contact phase in the backwards sprint, the main loading area was around the heel at position a-1, with a maximum value of 203 kPa. The main loading was under the toes (a-1 and b-1) in the maximum pressure phase, reducing to the heel. There was almost no load on the d-area.

In the backwards run, the maximum average load in the contact phase was observed in as 154 kPa with a maximum average load of 245 kPa (Figure 9).

![Figure 8](image)

(a) contact phase       maximum pressure phase

(b) contact phase       maximum pressure phase

**Figure 8:** An example of distribution of pressure on outside foot in turn, (a) experimental data and (b) averages for six male soccer players.
In the jump, the largest loading was observed on the heel area (area d) in the contact phase. The large load areas were widely distributed in areas a and b in the maximum pressure phase (Figure 10). The peak pressures moved from the heel during contact to under the toes during the maximum pressure phase. During contact phase in diving, the take-off foot (the right foot), had main loading areas of b-3, d-2 and a-1. In the maximum pressure phase, the main loading areas were b-3, b-2, b-1 and a-2. In the case of the support foot (the left foot), the main loading area was b-1 for both the contacting and maximum pressure phase. It is the tendency, therefore, that the value of the maximum loading point of the supported foot is greater than that of the take-off foot.

In the maximum pressure phase in the jump, high average peak pressures were observed in a, b and c-3 areas and a similar tendency was observed in diving.

In the vertical drop test simulation, the contact time of the foot model and the floor model was approximately 22 ms, and the vertical peak force was approximately 8400 N (for the model weight of 60 kg) suggesting that the experiment represents a good approximation of real life (Nishiwaki and Nasako, 1998). However, the vertical peak force for this boundary condition was much higher than that reported for an actual running human (Nigg, 1986; Lafortune and Lake, 1995).
the inside impact simulation was lower than that of the outside impact simulation, and the timing of the vertical peak force of the inside impact simulation was later than that of the outside impact simulation. Especially, the initial ground reaction force of the outside impact simulation indicated a small value. These results suggest that the stiffness of the inside is higher, and the dispersion of energy is lower, than that of the outside in the foot complex. It is considered that the characteristics of the stiffness of the foot complex involve the role of the first metatarsal head and the hallux in fundamental human motions.

Obviously, the ground reaction forces of these simulations depend on the quality of the model structure and material properties. The material properties in this study are based on simple assumptions.

SUMMARY

The foot pressure distribution analysis in this study shows that, in the majority of movements in football, peak forces are experienced under the first metatarsal head or hallux. This has implications for football shoe design. For a comfortable impact with the ball, a stiff upper surface is required. For a comfortable impact with the ground the combination of a stiff sole with cushioning under the 1st metatarsal is desirable. It appears that the peak forces do not move far from these regions except in the jump. In the contact phase, a specific tendency was not observed for the foot pressure distribution. In the maximum pressure phase, the maximum vertical peak pressure was observed on the area of the first metatarsal head or the hallux in football specific movements such as sprint, backwards run, side step, turn, and dive. It is considered that the first metatarsal head and the hallux play an important role in the fundamental movements in football and boot design should have the combination of outside stiffness for comfortable impact with the ball and surface and interior cushioning, particularly around the first metatarsal.

In the computer simulation to analyze the stiffness of the foot complex at the oblique impact using the finite element method, it is considered that the stiffness of the inside is higher, and the dispersion of energy is lower, than that of the outside in the foot complex. These results suggest that to the stiffness of the inside is higher than that of the outside in the foot complex is one of the reason why the first metatarsal head and the hallux play an important role in the fundamental movements in football.

REFERENCES