COULD KOEHLER-FREIBERG’S DISEASE BE CAUSED BY BIOMECHANICAL FACTORS?

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SUMMARY
Koehler-Freiberg's disease, an idiopathic necrosis of the metatarsal head, most commonly occurs in the 2nd, sometimes in the 3rd and relatively seldom in the other rays of the foot. Investigations regarding the possible causes of the disorder have led to an enquiry into the biomechanics of the metatarsophalangeal (MP) articulations. A search through the available literature did not reveal any information that could be directly applied and therefore a series of experiments were performed to determine a) the ground reaction on the MP joints and on the toes, b) the direction of the flexors and other tendons that cross the joint which might be responsible for the force acting between the toes and the ground, c) the geometry of the joint surfaces and finally, d) the force crossing the joint between the head of the metatarsal and the corresponding phalangeal bearing surface.

It is shown that the force per unit area, or specific loading, of the MP joint of the 2nd ray could amount to about twice that which occurs in the same articulation of the great toe. This might well explain the higher occurrence rate of osteonecrosis observed in the 2nd ray compared to that in the 1st. Furthermore, it is shown that the resultant joint force in the MP joint of the 2nd ray is more dorsally directed than that of the 1st, which coincides very well with clinical observation.

Finally, a finite element stress-analysis has been performed to investigate the stress situation within the metatarsal head under concentrated load-bearing conditions. This has shown that possibly the cancellous bone would collapse under repeated loading, leading to the well-known appearance as first reported independently by Koehler and Freiberg over 60 years ago. Thus under certain conditions where high specific loading of the metatarsal head can occur, for instance through edge loading due to subluxation of the phalangeal bearing surface, it is quite probable that osteonecrosis in the immediate vicinity of force transmission would ensue.

INTRODUCTION
The changes in the bone structure and form of the metatarsal heads as they appear on X-rays that are characteristic of Koehler-Freiberg's disease raise the question as to whether the action of mechanical forces play a decisive role in the development of this ailment since, as is long known, the architecture of bone can well be induced to undergo alterations dependant on the external forces applied (Wolff, 1892). Investigations relating to the blood vessels in this area have shown qualitative differences in the localisation and the extent of coverage amongst normal feet but no quantitative indication was found to explain why, for instance, the disease attacks usually the 2nd and 3rd metatarsals and less commonly the 1st (Zollinger and Kubik, 1984). Although it has been shown that wide-spread bone necrosis could be caused by deficiency of the blood
supply, necrosis of the localised type, such as in osteochondrosis dissecans, in which case a small portion of the joint surface becomes detached from the rest and eventually floats as a separate entity within the articulation, is difficult to explain. This type of lesion, sometimes encountered in the 1st ray (Fig. 1), is almost exclusively seen in the remaining metatarsal heads, in which cases it is more dorsally located than the position observed when present in the 1st metatarsal.

Fig. 1: A case of osteonecrosis dissecans of the first metatarsal head

The appearance of these subchondral bone lesions is indeed very reminiscent of the surface fatigue phenomenon commonly known in mechanical engineering as "pitting", which is due to the repeated action of concentrated loading on the surface of an object at almost a point (Hetenyi, 1963). Therefore, it was decided to investigate the mechanical conditions to which the articular surfaces of the metatarsal heads were exposed under physiological conditions in an attempt to perhaps find an explanation for the bone lesions already described, in this manner.

On commencing this task, it became quickly evident that many of the anatomical, topographical, and mechanical details that were required to determine the forces acting across the joint were not available from the literature known to us and therefore we obtained the required information by carrying out the relevant detail-investigations ourselves. These have been reported at length elsewhere (Jacob et al., 1985) and it is the purpose of this report to present the methods employed and, based upon a finite element analysis only recently completed, to describe the probable manner in which the pathological condition evolves.

INVESTIGATIONS PERFORMED

In order to determine the forces that act across the metatarsophalangeal (MP) joints, it is necessary to determine the external forces acting on the toes. This was done as follows:

By observing the geometry of the joint surfaces and by determining the exact position of the tendons relative to the centre of rotation of the MP joint, the force in the tendons necessary to produce the ground reaction force at the ends of the toes can be estimated. The tendon force together with the ground reaction force then leads to the required force across the MP joint.

The plantar forces acting at the distal end of the 1st and 2nd rays were measured by means of transducers that were specially built, employing strain gauges. Four transducers were used, one under each MP joint and one in the contact area between the toes and the ground. The transducers were sensitive only to vertical loads, i.e. only the vertical component of force was obtained. They were built into a cork sandal as shown in Fig. 2. The sandal was so formed as to allow walking in a comfortable manner. The sandals were not flexible so that practically no dorsal flexion occurred in