This paper is to be devoted to the history of footgear, and its effect on the human foot.

Man is born barefoot, and barefoot he compassed the earth. Therefore, it should be to barefoot peoples that we should turn to study the natural anatomy and physiology of the foot to obtain a base for the study of footgear. Wells\textsuperscript{96} has given a good description of the anatomy of the foot in barefoot Bantus and Bushmen. From extensive observations throughout the world,\textsuperscript{88} I should like to point out that:

1. Untrammeled feet vary in width, length, and thickness according to heredity.

2. When standing, the toes tend to lie in the line of their metatarsals; however, the distal phalanges of the 4th and 5th toes frequently have a prehensile curl toward the midline of the foot (Fig. 1).

3. Peoples unhampered by European traditions, or deforming Asiatic customs, walk with the axes of their feet approximating the line of progression.

4. Normal human gait is a smooth sequence of events recurring about 60 times a minute, which, much like the heart, has a resting phase — the swing — and a working phase — the contact or standing phase as was confirmed by the Inman and Sheffield groups\textsuperscript{19, 53, 81, 104}; hence, walking is more restful than standing.

5. When walking, the heel always makes the first contact, followed by the outer border of the foot, and finally the ball of the foot and then the toes. This was demonstrated by Schwartz and his coworkers on shod individuals.\textsuperscript{77–79} This slight rolling motion is observable grossly. It permits the foot to adjust to surface irregularities, and provides the silent tread essential to primitive hunters.

6. The toes hyperextend slightly before the contact, remain extended during contact, and seem to tense as contact is about to be broken.\textsuperscript{38}

7. Except in sand and mud or on rocks,\textsuperscript{88} the hollow arch seldom seems to touch the earth.

8. The toes are used by unshod peoples for grasping.

No strictly experimental data is available on the effects of shoes on feet, nor could it ever be available except under a heartless depositism. We have to depend on the observations of those who have lived and worked with shod and unshod peoples. All writers who have reported their observations of barefoot peoples agree that the untrammeled feet of natural men are free from the disabilities commonly noted among shod people — hallux valgus, bunions, hammer toe, and painful feet.\textsuperscript{26, 33, 60, 61, 88, 100} Shine\textsuperscript{82} comparing isolates, some of whom went barefoot and some who wore the limited choice of shoes available in their island store, remarks on the frequent occurrence of deformity among the shoe wearers. Möller, an orthopedic surgeon of Johannesburg, in personal correspondence, told of the rarity of foot problems in the barefoot Bantu laborers of earlier years, compared to the great frequency of foot problems among the shod Bantu laborers of today. The professional photographer who prepared the cuts for this paper remarked: “When I came to the islands years ago my toes were all bunched together on top of one another but after I
began to go barefoot and wear sandals, they all straightened out." Certainly the intimate environment of the foot is more likely to affect the shape and function of the foot than some remote factor.

The deleterious effect of footgear is backed up by the Army Shoe Board—under Major Munson. In 1908 they took a battalion of men shed with shoes of their own choosing, marched them 8 miles one day and back, the next. All feet were examined at the close of each day's march; 30 per cent had severe injuries at the end of the first day, and 38 per cent at the end of the second, some requiring hospitalization. Major Reno found that only 26 per cent of 531 men were properly shed. In another group of 609 only 16.5 per cent were properly shed. These figures would indicate that the majority of people don't know when they are properly fitted. Later the Board took 8 companies of infantry, examined their feet and fitted them with shoes. Two weeks were allowed for breaking them in. Then they were marched 117 miles in 9 days carrying field equipment. The feet were inspected daily; 26 men were transferred to other units during the march. The remaining 352 completed the march without serious disability. This would indicate the value of properly fitted shoes.21

Are Shoes Necessary? The Indians of Terra del Fuego, according to early observers, spent their wretched, frigid lives with only a skin thrown over their shoulders.10, 23, 39 The Bushmen of the Kalahari (Fig. 2) and the Aborigines of Australia pursue game over torrid deserts without a thought of their feet. Coon20 reports recently their use of sandals on occasion for tracking or among sand dunes. The corium of the unshed Bantu's foot is 6–9 mm thick.97 Millions of Indians, both American and Asian, and Congoids wander their native savannas and rain forests without protection, inconvenience, or complaint. Footgear, therefore, would appear to be unnecessary.
Why Was Footgear Developed? The earliest trace of footgear known to us was found in caves and rock shelters, near Fort Rock, Oregon, under a layer of volcanic ash deposited by Mt. Newberry. The sandals were made of sagebrush bark, or tules (Fig. 3). Originally they were carbon-dated to about 9000 B.C., but the discovery of the Bristlecone phenomenon increased their probable age to nearer 10,000 B.C. Their perfect craftsmanship bespeaks a long heritage of purposeful design and satisfactory use. The foot surface is smooth, the tread reminds one of a snow tire. They were held on by bast loops over the instep. At the time they were made, south central Oregon although actively volcanic was studded with marshy lakes. Judging by the mud on the sandals, they were evidently used for hunting in the slippery marsh. After the hunt, the sandals and broken gear were discarded under the shelters where they were found.

Sandals of comparable structure, but of different bast, and different retentive mechanisms were used throughout volcanic cordilleras of Meso- and South America and the volcanic islands of the Pacific. Many years ago when working in the Bishop Museum the late Sir Peter Buck told me that every Polynesian when preparing to cross an old lava flow would take with him at least 30 pairs of sandals, so rough was the going; they also wore them when fishing on the reef to protect their feet from painful, slow-healing cuts of the razor-sharp coral. Sir Buck also showed me a pair made of slabs from the sides of coconut husks. This was worn convex side down by persons with injured feet, so that they could rock along.

Pan-Pacific sandals were unpaired, except perhaps by the location of the interdigital thongs. Most retentive mechanisms included loops along the side which were caught together over the instep and around the ankle, to prevent their loss in moving water. Some Peruvian sandals had a broad strap over the instep with a strap-like thong of bast around the heel with sub-malleolar anchors. Therefore, the prime function of the earliest sandals was protection of the sole.

Early riverine peoples dwelling on the alluvial soils of the Euphrates, Nile and Indus went barefoot for the most part. The early Pharaohs are all represented as barefoot, though sandals must have been known in the middle of the 3rd millennium B.C. for they are attributed to the gods in a Pyramid text. By the middle of the second millennium B.C. sandals were in frequent use in Egypt, using wood bast and leather for soles. In the first millennium they were being used in Mesopotamia by the court and soldiers.

Retention was obtained generally by the Egyptians by a T or V thong passing through the sole between the great and 2nd toes.
where it was fastened by a massive, uncomfortable knot that bespeaks only occasional use and permitted easy removal. The Pharaoh had an official sandal bearer and Tutankhamen was buried with a chest of sandals of several types: papyrus for religious functions, a leather pair tooled with the images of a Semite and Negro—presumably symbolic of treading his enemies beneath his feet, and a jeweled ceremonial pair. No wonder, as the Pharaoh went from precinct to precinct, and ceremony to ceremony, he needed an official sandal bearer. Among the priestly sandals which have come down to us is a wooden pair elevated on delicate piers. Much like the more sturdy getas introduced into Japan about A.D. 600 to keep the owner out of the mud.

In Mesopotamian kingdoms sandals were evidently a status symbol, for Assur-nasirpal, 883 B.C., is shown with moderate wedges in contrast to his flat-soled courtiers. These sandals had a high triangular counter with loops along the edge; a thong looped through the sole and around the great toe, crossed over the instep and was caught through the loops and tied. Their use was evidently more continuous than among the Egyptians.

None of the footgear described would interfere with the shape or functions of the foot and we shall refer to them as sandals. Some modern sandals are in reality shoes for their soles are not cut to the shape of the foot and straps, or nets cause the toes to clump together in a deformed position.

The Greeks of this period paired their shoes by cutting the soles around the weight-bearing foot. The upper varied with the fancy of the cobbler or the client; some were true sandals, other fancy shoes tended to hamper or deform the feet. I have noted incipient hallux valgus on some Greek statues.

In excavating the Agora they found a terra cotta model of an open-throated, thick-soled low boot which completely encased the foot and would interfere with intrinsic foot activity. The thickening of the sole went to an extreme in the cothurni where it has been
found as thick as the foot was long. These were used by tragedians to increase the height of the wearer. Comedians wore socks, or soccus — hence, the expression “high tragedy and low comedy.” These vagaries were held on either by an interdigital peg or by straps. Their temporary use would do no harm. The attempt to increase height persisted into the days of Shakespeare when chopines reached a vaulting zenith of 18 inches of asininity. The wearer had to be supported on either side. Thus, the secondary function of footgear appears to have been symbolic.

This brings us to era of painful feet. The Etruscans of the VII–VI centuries B.C. devised paired, tightly moulded, half-boots (Fig. 4), the upturned toe of which lay in the midline deflecting the toes toward the midline of the foot. These would tend to produce bunions. The snug lacing would tend to prevent normal functional swelling which would increase pain, as we all have experienced. The males of the period seem to have gone barefoot, except perhaps in the case of soldiers, for there has been found evidence of shoes that had metallic soles molded over thick wooden plates: they were hinged, evidently with a thick piece of leather. The soles were equipped with metal cleats. One pair had a self-cleaning mechanism in the hinge. Of their uppers we know nothing.

About 500 B.C. there were carved on the north staircase of the Apadana at Persepolis a procession of tribute bearers from every satrapy of the Persian empire, dressed in their native costumes. This is a veritable showcase of footgear. Here, for the first time, we see what appears to be high felt boots with turned up toes from the mountain satrapies. In Kashmir I have been offered dippers of similar shape on the pretense that they would prevent me stubbing my toes. I take it that the high boots were to protect against the cold.

In China and Japan the earliest pictures show men going barefoot. Among the nobility square upturned toes were worn. In India, the natives apparently went barefoot until after the coming of the Mogul emperors.

In the western world the styles of Greece, using short pointed shoes, were largely followed from the beginning of the Roman empire through the Age of Turmoil (406–1400). Tradition tells us that about the beginning of the present millennium Count Fulk of Anjou introduced long pointed toes to cover up some deformity of his feet. Courtiers adopted the fad, necessitating sumptuary laws to regulate the length of the toes — the higher the rank the longer the toes. Anne of Bohemia (1366–1394) had to fasten her toes above her calves with golden chains. Petrarch in 1348–49, when writing to his brother, complained of the pain caused by his shoes and stated that he would prefer to go barefoot — a scandalous thing at that period.
During this same period the Persians developed the finest miniatures in the world. These were highly conventionalized paintings of legendary events and persons. They showed the Persians as a slippered people except for the mounted individuals who wore boots, and frequently Mongolian helmets. Among these miniatures are at least one of each of the great conquerors — Chingis Khan, Hülegü, and Tamerlane (Fig. 5) — all dressed in Persian dress, except instead of slippers they are booted with block heels. As far as I can determine, this is the first representation of heels and they appear in no other of the early miniatures, but do appear in the century after the death of Tamerlane. Heels reached Europe in about the 16th century. The early European heels were largely flat. The French began to elevate the heels to lend height to the wearer. In the foppish court of the fingerling Louis XIV, high heels were adopted by the whole court and reached their ultimate idiotic proportions in the recent spike heels.

What was the reason for the introduction of the heel in the first place? Lamb suggested that the heel was used to grip the stirrup plate. What was the object of the stirrup plate? The Chinese word for stirrup is also the word for "to mount" and they are so used by all saddle-using peoples. Once mounted, the warrior could use them as a platform to steady him in standing to use his weapons. However, most horsemen that I have consulted state that to let the foot slip forward till the heel caught on the stirrup plate would be to invite disaster.

Another possible cause for the introduction of the heel was that it was a prosthesis. With hundreds of thousands of casualties in the campaigns of the Mongols it is probable that many received wounds from which they recovered. Considering the standards of practice, even in my early years, it is likely that a number recovered with a foot drop. It
Fig. 6. Tracing of X-rays showing angular and length changes between barefoot and foot wearing 9-cm heel. Same model. BB'—ankle height; CC'—calcaneal axis; LL'—basic foot length; MM'—metatarsal axis; TT'—talar axis; AD—basic effective length to determine leverage; TOM—metatarso-talar angle; HC—metal heel core.

**INTERPRETATIVE CALCULATIONS**

Changes in length of foot.

\[ A(\text{LL}') - B(\text{LL}') = 16.75 - 15.8 = 0.95 \text{ cm shortening when heel is introduced.} \]

Changes in leverage.

\[ \frac{\text{BL}' \times 100}{\text{LL}'} = \frac{11.6 \times 100}{16.7} = 69.5 \]

\[ \frac{\text{BD} \times 100}{\text{AD}} = \frac{6.4 \times 100}{12.6} = 50.0 \]

\[ 69.5 - 50.0 = 19.5 \]

\[ 19.5 / 69.5 = 28.0\% \text{ shortening of leverage.} \]
TABLE 1.

<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>9-cm Heel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of foot</td>
<td>16.75 cm</td>
<td>15.8 cm</td>
</tr>
<tr>
<td>Leverage index</td>
<td>69.5</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Angles are measured on a 360° protractor with the 90°–270° axis parallel to the ground.

- Calcaneal axis         | 248°     | 282°      |
- Metatarsal axis        | 290°     | 343°      |
- Talar axis             | 290°     | 325°      |
- Talo-metatarsal angle  | 0        | 18°       |

would not seem unreasonable to believe that someone would find that a block under his heel would make walking easier. Of the leaders portrayed, only Tamertane would come in this category.42, 43 Concerning his disability there is some dispute, which at this distance in time we are unable to resolve.44, 45

Since the heel first appears artistically only on the three Mongol leaders long after their deaths, it would seem to me that the heel was first used in the miniatures as symbolic of a crusher. This imagery has been used since Biblical days.

What are the effects of heel wearing? This can best be judged by looking at the extreme cases — from barefoot to a 9-cm heel (Fig. 6). An analysis of the weightbearing foot of a female may give some clues. Elsewhere, we have described the method of making such an analysis.46 Each foot would have its own indices, and the indices would vary with the height of the heel (Table 1).

The 34° change in the calcaneal axis in this individual shortened the contractile length of the triceps surae 2.5 cm, locked the talus in the ankle mortise, and caused the development of the 18° angle between the talar and metatarsal axes, thereby shortening the foot by 0.95 cm with a corresponding shortening in the contractile length of the plantar muscles. The leverage of the foot was reduced by 28 per cent. Body weight was transferred largely to the sesamoids predisposing to the heavy calluses seen in the women wearing high heels. The novice wearing high heels walks with a weak droop-knee gait; the votaress sustains a structural shortening of the calf muscles which makes unheeled walking difficult.

High heels also present a functional problem when climbing stairs. The average person when ascending stairs places the ball of the foot on the next tread, under weight bearing the heel sinks slightly maintaining sural tone. The high heel wearer places her whole foot on the tread to avoid catching her heel, hence loses sural tone and stair climbing becomes labious.

As long as shoes were being custom-made, the next problem did not appear, but with the standardization of lasts in mass production some shoe wearers run their shoes off to one side. This is exaggerated by the wearing of even moderate heels. Observers of the passing parade will note that the heels of some sling-heel wearers ride off the shoe; closed-heel wearers tilt their heels to one side. Both tell the same story — the shoes weren’t made to fit that person’s feet. Until stiff counters were introduced in the last century this created a messy appearance. The messy appearance, however, might be replaced with a painful strain, which can be relieved by a sling heel.

After the Louisian splurge of vanity, men’s
heels tended to flatten out, while women's heels tended to increase in height in some instances.

High, slender heels are intrinsically unstable, tending to either kick out behind or fold under the arch. When worn, their lateral instability is abetted by the subtalar joint, predisposing to ankle injuries. To remedy the anteroposterior instability a metal shank was introduced in the 19th century.

European peasants wore clogs carved to comfort from a block of wood. Mass production seems to have begun prior to the 14th century, for Edward II in 1324 decreed that shoes should be sized. Their length was measured in barleycorns, 3 to an inch. This is still the basis of shoe measurements. \( \frac{1}{2} \) inch to a size in length. We, however, start sizing from a base line of 3" in children and 7" in adults. Widths vary with length, in a given size the widths vary by 1. 12 inch.

Unpaired shoes were introduced in England in the 15th century when gout became common. The toes were made broad and square and were slashed to relieve painful pressure. This also brought forth sumptuary laws. Unpaired shoes were still being made at the beginning of this century.

The most recent innovation seems to have been the hard box toe to preserve the appearance of the shoe. In industry a steel box toe is sometimes required to prevent toe injury. The box should be high enough to permit toe motions.

In the neolithic age, primitive man seems to have sought occasional protection for his soles; civilized man seems to have sought ways for distinguishing his status through the use of shoes, some of which protected him and others deformed his feet or made them painful. The highly trained surgeons of civilization have sought to remedy man's self-inflicted woes, not by turning back to the point of departure, but by imagining unnatural remedies. The soft, delicate skin of the arch when compared to the harsh skin of the ball, heel and outer border should have taught orthopedic surgeons that the arch is not commonly a weightbearing part and that there is no need for plates and pads.

The remedy for man's foot pains, I believe, lies in the more natural physiological use of his feet. I have observed painful feet as the result of the increased strain caused by a mild Chaplinesque shuffling gait. The increased strain is confirmed by the work of Mann and Inman in electromyography. More than a century ago, children were taught that this was the proper way to walk, and even at the close of the last century I was so taught.

Shoe wearing is a prerequisite of the modern western business and social world, and the use of shoes is fast spreading, as a status symbol, to more primitive peoples. We should learn from primitives the pleasure and painlessness of going barefoot, or the use of simple protective soles as the Japanese zori, or the T-sandals of the ancient Egyptians. We should learn from the Japanese the value and pleasure of going barefoot or sockfooted in the privacy of our own homes.

Since western man seems set on abusing his feet, perhaps it would be wise to learn something from the Army Shoe Board. It observed that the feet of soldiers, when carrying their field equipment, increased in length and breadth as much as half an inch. This would indicate to me, that the foot's shape was maintained not only by bones and inelastic ligaments, but by powerful musculature, particularly the intrinsic muscles as the abductors of the great and little toes. The ascribed names reflect dissecting room physiology. These beliefs are substantiated by the electromyographic studies of Inman and his co-workers. However, their work is incomplete for they did not investigate the muscular activity of the foot when wearing high heels, which is not synonymous with standing on one's toes.

The lessons learned by the Army Shoe
Board, including some feminine considerations, are as follows:

1. The shoe should be at least a size longer than the measured length of the weightbearing foot.
2. The tip of the shoe should lie well to the halluxal side of the shoe, not in the midline where it is frequently seen.
3. The shoe should fit the waist of the foot (the part just proximal to the heads of the metatarsals) snugly enough to prevent anteroposterior shifting.
4. The part covering the toes should not restrict the motions of the toes, or cause their displacement; X-strings over the toes are especially vicious in causing displacement.
5. The counter, whether stiff or strap, should fit the heel snugly.
6. The wearer's heels should rest fully on the heel of the shoe, which should be large enough to be stable.
7. The heels should be as low as possible to insure stability and reduce the likelihood of injuries.
8. Esthetical fitting generally results in painful feet.

SUMMARY

A study of the structure and history of footwear from the earliest times points out the ways in which innovations influence physiologic function.

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