児童、生徒の足跡に関する研究：発育現象における土踏まず・母趾角の出現とその意義

A Study on Foot-sole of Children and Students in Okinawa

... Appearance of plantar arch and hallux angle
in the growth phenomenon and its significance ...

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Abstracts

In Ie village of Okinawa Prefecture we collected foot-sole replicas of children and students aged between 6 and 15 years for measurement and analysis and studied the growth of the foot-sole and significance of appearance of the plantar arch and hallux angle. The rate of the plantar arch formed, width of the sole, width of the heel and the size of the hallux angle were closely related to the difference in the process of growth between boys and girls.

The delay in formation of the plantar arch is thought to be due to the delay in the phenomenon of ossification and insufficient practice of walking movement. Thus, formation of the plantar arch was considered important in examining the growth of the foot. The time for the hallux angle to be formed is closely related to completion of the 3-dimensional structure of the foot in the horizontal direction and an increase in the body weight.

Particularly in girls, the hallux angle is formed at a time when the growth of the 3-dimensional structure of the foot and improvement in physical condition are ill-balanced.

Therefore, the hallux angle was considered important in examining the way the burden of the 3-dimensional structure of the foot is borne and the abnormality in the way of walking.

Introduction

There appear to be two major directions in the process of the growth phenomenon. The first direction is one which grasps the process of the growth phenomenon within the framework of an individual of the living things.

According to Takaisi[1], the following three general principles can be seen in the process of the growth phenomenon. That is, (1) the growth phenomenon is a continuous process, (2) an almost fixed order is seen and the order has a basic direction, (3) the individual difference is

very large. These principles serve as a good indicator in grasping the growth phenomenon.

For instance, the developmental order of the motor function of man from"setting of the neck", "standing on his legs" to "walking by himself" is a good example to corroborate with the principle under (2).

The second direction is one which grasps the process of growth phenomenon as the process of evolution of species of the living thing concerned. Generally, the phrase "the process of growth phenomenon" is liable to be used for the growth phenomenon as an individual of living things mentioned earlier.

However, it should not be overlooked that the process of all growth phenomena is based on this.

Mizuno[2] said "Children run after the trail of human evolution throughout the period of their growth. The width of foot gets narrower gradually against the length of foot and the instep becomes increasingly higher to form the foot arch. "This shows that the growth phenomenon of the foot is concerned with evolution. Mention may be made of "standing upright with two feet" and "walking with two feet" among what man was able to acquire in the process of his evolution.

It is generally said that man let his hands free by standing and has built civilization as it is today.

Of the two, "standing upright" is basically more important than "walking". This is understandable in the light of the general principles mentioned earlier.

As to "walking" too, for man to become able to master free ways of walking such as jumping sideways, changing the speed forward and backward and changing direction in addition to merely walking straight ahead is a great progress and high technology that was made possible for the first time in man.

In recent years, however abnormalities in the growth phenomenon hitherto not observed such as "the delay in formation of the plantar arch" and "unnatural way of walking" have become conspicuous among children, while daily life has become very convenient with rapid urbanization attendant upon the progress of science and civilization[3].

As to such abnormalities in the growth phenomenon of the foot noticed in children, Noda et al[4] have pointed out that it might be due to "the foot not being used sufficiently".

This view sounds reasonable considering that the urban living environment as seen today is approaching an environment where people can walk without much effort; that is, people take a street-car, bus or taxi to a place which is within easy walking distance, and the so-called "walk-saving machines" such as elevators and escalators are available at the railway stations and department stores.

The situation of "being unable to stand well and walk" may manifest itself as the "delay in formation of the plantar arch and unnatural way of walking".

Ie village investigated in this study is an island located about 9 km northwest of the Motobu

Peninsula in the northern part of Okinawa proper. The total area of the island is about 23 km^2 with a population of 5,582 as of the end of March, 1985. It is a farm-village type region, with sugar cane as basic industry. The village has 2 elementary schools - affiliated kindergartens and 1 junior high school, the number of children and students being about 900. Not much difference is seen in the living conditions of children and students on such a tiny island, which provides an environment suitable for observation on the growth development phenomenon. We studied the significance of appearance of the plantar arch and hallux angle in the children and students by collecting the replicas of their foot-soles for measurement and analysis.

Subjects and Methods

1) Subjects

The subjects selected are 98 kindergarten pupils, 546 elementary school children (1st ~ 6th grade) and 255 junior high school students (1st ~ 3rd grade) which totals 899. The details are as presented in Table 1.

Table 1 subjects

School year		Boy	Girl	Total
Kindergarten		53	45	98
Elementary	1st grade	63	44	107
school	2nd grade	38	50	88
	3rd grade	42	35	77
	4th grade	48	43	91
	5th grade	58	40	98
	6th grade	45	40	85
junior	1st grade	47	40	87
high school	2nd grade	43	37	80
	3rd grade	39	49	88
Total		476	423	899

2) Methods

(1) Method of collecting replicas of the foot-soles

Using a set of Pilot Co.— make hand print-collecting paper, replica of the foot-sole was collected as follows : The subject is first made to sit on a chair so that his feet do not touch the floor. The plantar surface on both sides is moistened evenly with a napkin impregnated with a coloring solution.

Thereafter, the subject is asked to lower his feet on a white paper placed on the floor so that the surface of the floor is parallel to the plantar arch and then to stand upright in a comfortable posture.

After having the subject stand upright for about 5 seconds, a foot print that came out in

blue-purple on the paper was used as the replica of foot-sole.

(2) Method of measuring the foot-sole replica

With lines A, B, H, points D-G, point M and angle Z set on the foot-sole replica as illustrated in Fig.1, the Hirasawa type judgment of the plantar arch and measurement of the width of foot-sole (DE length), width of the heel (FG length) and hallux angle (angle Z) were made.

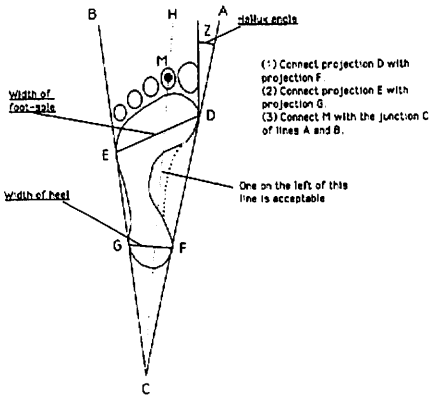

Fig 1. Method of measuring the foot-sole replica

(3) Items measured

① Classification of how the plantar arch is formed by the Hirasawa type method of judgment on the plantar arch

The plantar arch was judged to be formed when the line of the plantar arch (dotted line) goes beyond the line H and not formed when the line does not go beyond the line H or contacts the line.

The plantar arch was classified as type A (not formed in both feet), type BL (not formed in only left foot), type BR (not formed in only right foot) and type C (formed in both feet) according to how the plantar arch is formed in both feet.

② Height, body weight

③ Rohrer's index

④ Width of the foot-sole (DE length)

⑤ Width of the heel (1FG length)

⑥ Hallux angle (angle Z)

Results

1) The rate of plantar arch formed by school year in children and students

The appearance rate of type C (formed in both feet) classified by the Hirasawa type method of judgment on the plantar arch from the foot-sole replicas collected was used as the rate of plantar arch formed and illustrated in Fig.2, by sex. When the difference in the formation rate between boys and girls was examined, girls from 1st to the 5th grade of the elementary school showed superiority in the formation rate.

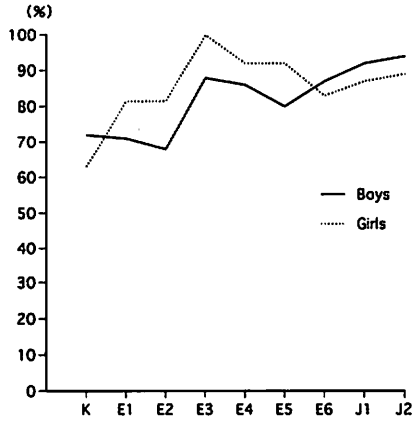

Fig: 2 The Rate of plantar arch formed by school year in children-students

In boys, the formation rate tended to become high as they advanced to higher grades and reached a peak in the 2nd grade of the junior high school.

In girls, the formation rate tended to become high as they advanced to higher grades as in boys; but, the formation rate reached a peak once in the 3rd grade of the elementary school and fell off slightly thereafter.

2) Changes in the growth-physical condition by school year in children and students

Table 2 Growth-physical condition of those in whom plantar-arch has been formed (mean value)

(Boys)

school years		Height (cm)	body Weight (kg)	Rohrer's index	Foot-sole width (cm)		Heal width (cm)		Hallux angle (degree)	
					Left	Right	Left	Right	Left	Right
Kindergarten		104.29	18.80	168.06	6.79	6.77	3.81	3.76	2.47	1.61
Elementary	1st grade	112.70	20.00	140.03	6.83	6.85	3.80	3.80	4.05	2.00
school	2nd grade	123.35	25.30	134.50	7.55	7.55	4.00	4.05	3.90	4.40
	3rd grade	126.95	27.00	132.22	7.70	7.80	4.05	4.15	4.15	3.10
	4th grade	132.05	28.70	124.86	7.90	7.90	4.30	4.45	3.94	1.65
	5th grade	138.40	34.80	131.38	8.35	8.35	4.55	4.55	4.75	4.75
	6th grade	143.40	37.60	127.53	8.60	8.50	4.60	4.60	5.05	3.20
junior	1st grade	147.30	42.50	132.97	9.00	9.00	5.00	5.00	4.80	3.30
high school	2nd grade	157.80	48.00	122.15	9.30	9.30	5.00	4.90	5.20	5.10
	3rd grade	162.30	52.70	123.26	9.20	9.20	5.00	5.10	5.00	4.20

(Girls)

school years		Height (cm)	body Weight (kg)	Rohrer's index	Foot-sole width (cm)		Heal width (cm)		Hallux angle (degree)	
					Left	Right	Left	Right	Left	Right
Kindergarten		109.25	18.20	140.12	6.65	6.57	3.60	3.55	1.90	1.03
Elementary	1st grade	133.15	20.40	141.15	7.04	7.00	3.96	3.93	4.25	3.21
school	2nd grade	121.75	24.30	134.98	7.35	7.35	4.00	4.05	3.25	2.55
	3rd grade	125.95	25.70	128.89	7.45	7.40	4.05	4.05	6.20	5.80
	4th grade	133.35	30.10	127.26	7.85	7.80	4.24	4.38	4.97	3.42
	5th grade	140.45	33.80	122.11	8.05	8.10	4.40	4.45	8.75	8.05
	6th grade	144.55	40.60	127.29	8.60	8.45	4.65	4.80	7.95	6.30
junior	1st grade	151.60	45.00	129.15	8.40	8.50	4.80	4.70	7.10	6.10
high school	2nd grade	151.60	44.90	128.86	8.50	8.40	4.60	4.60	6.70	6.40
	3rd grade	151.10	48.10	139.42	8.50	8.40	4.70	4.80	9,10	6.20

Table 2 shows the height, body weight and results of measurement of the foot-sole replicas in those who were judged to be type C (formed in both feet) from ①. The growth curves for the gradewise height and body weight of children and students illustrated in Fig.3 indicate that physical conditions improve with the advance of grade in both boys and girls.

In Fig.4 are illustrated changes in the Rohrer's index by sex and school year on the basis of height and body weight. A look at this figure shows that the Rohrers index becomes low from kindergarten, 1st grade through the 3rd and 4th grade, tends to level off from the 5th grade of the elementary school to the 1st grade of the junior high school in both boys and girls and tends to increase again only in girls there after.

3) Changes by school year in the width of the foot-sole, width of the heel and hallux angle

Fig.5 to 8 show the width of the foot-sole, width of the heel and hallux angle by sex, right

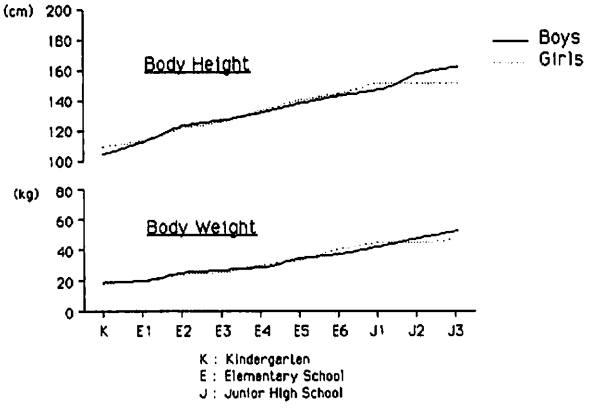

Fig 3 : Changes in growth-physical conditions by school year

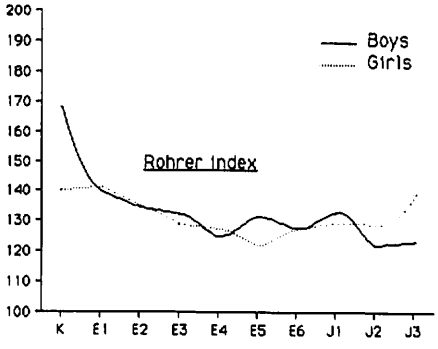

Fig 4 : Changes in Rohrer's index by school year.

and left as measured from the foot-sole replicas for each school year.

As seen in Fig.5-1, both the width of the foot-sole and width of the heel tended to increase as the grade advanced in boys, but the width of the foot-sole from the 2nd grade of junior high school and the width of the heel from the 1st grade of junior high school almost levelled off.

The difference in the width of the foot-sole and width of the heel between the right and left was not distinct.

As seen in Fig.5-2, both the width of the foot-sole and width of the heel tended to increase as the grade advanced in girls as in boys, but almost leveled off from the 6the grade.

The difference in the widht of the foot-sole and width of the heel between the right and left was not distinct as in boys.

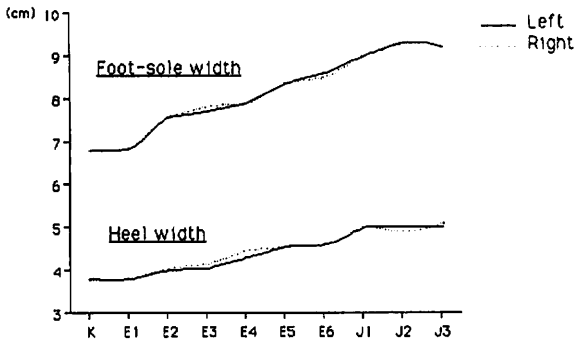

Fig 5-1. Changes in foot-sole width, heel width by school year (boys).

Fig 5-2. Changes in foot-sole width, heel width by school year (girls).

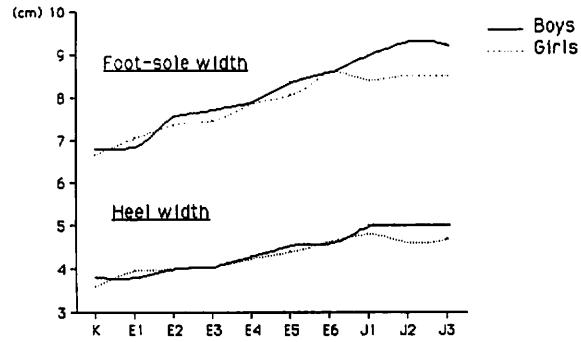

Fig 6-1. Difference between boys and girls in the foot-sole width, heel width (left foot).

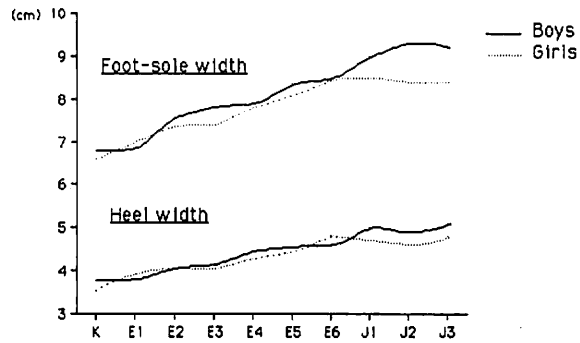

Fig 6-2. Difference between boys and girls in the foot-sole width, heel width (right foot).

Fig.6-1 and 6-2 show comparison of the width of the foot-sole and width of the heel by the right and left in boys and girls. As clearly shown in the figure, the superiority of boys as to the width of the foot-sole was seen from the 2nd grade of elementary school, and the superiority was conspicuous particularly from the 1st grade of junior high school. As for the widht of the heel, differences between the sexes were not particularly seen up to the 6th grade of elementary school, but distinct differences between the sexes were observed thereafter.

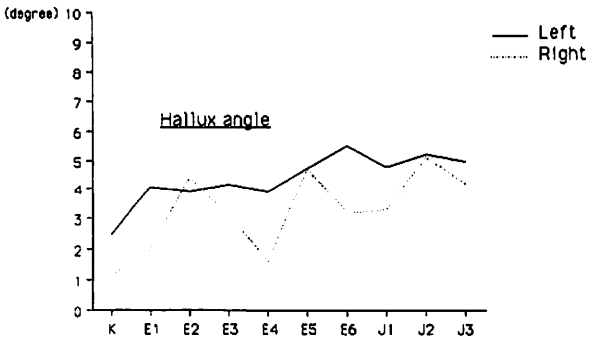

Fig 7-1. Changes in the hallux angle by school year (boys).

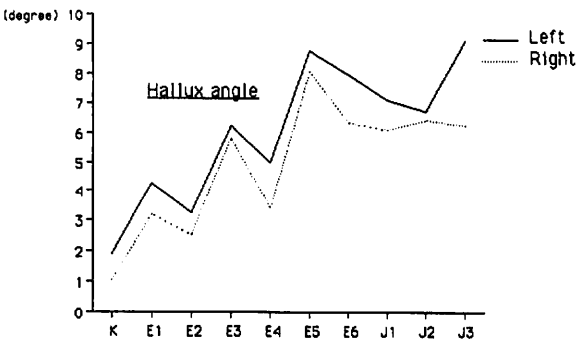

Fig 7-2. Changes in the hallux angle by school year (girls).

Fig.7-1 and 7-2 show comparison of the hallux angle on the right and left by sex. In both sexes, the left hallux angle was larger than the right hallux angle.

In girls, the hallux angle tended to expand with advance of grade. The hallux angle in boys tended to expand slighthly, thought not so distinct as in girls.

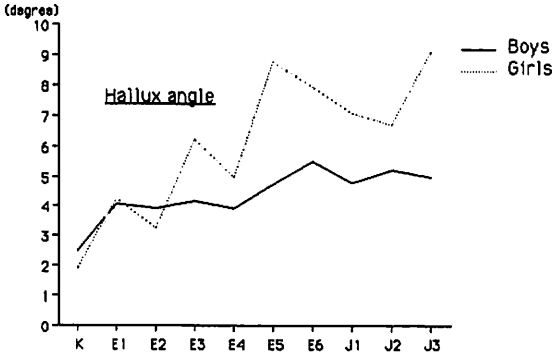

Fig 8-1. Difference between boys and girls in hallux angle (left foot).

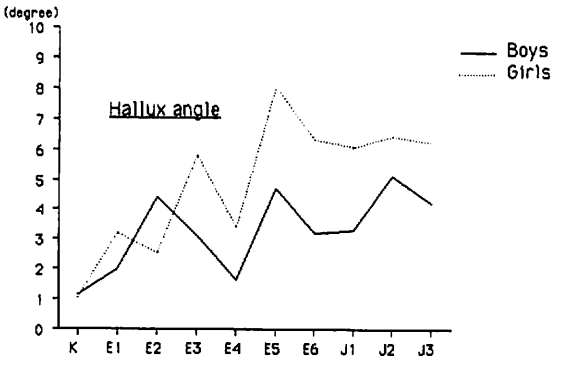

Fig 8-2. Difference between boys and girls in hallux angle (right foot).

Fig.8-1 and 2 show comparison of the hallux angle by the right and left in both sexes. As can be seen clearly from the figure, the hallux angle either on the right or left is much greater in girls from the 3rd grade on than that in boys.

Discussion

1) Difference between "flat-foot" and "no formation of plantar arch"as viewed from methodology

Mizuno[6] maintains that the so-called "flat-foot" is a word referring to the foot of which arch

structure is decreased and should be diagnosed from the aspect of the skeletal structure and that diagnosing the flat-foot with a foot print (foot-sole replica) is nothing but expedient method and does not necessarily reflect the decline in the arch structure of the foot. In short, the foot print (foot-sole replica) does not directly show the shape of bone but is influenced by the fat and development of muscle of the foot-sole; and, the flat-foot should be diagnosed by roentgenography.

However, the foot is examined to grasp the growth phenomenon in children, a foot print (foot-sole replica) may suit this purpose well. That is because the growth phenomenon of the foot should be judged not merely by the foot arch but comprehensively as the whole foot including fat and muscle.

As a matter of fact, it is only the plantar arch in the foot print (foot-sole replica) that poses a problem.

Considerably large amount of information can be obtained from the foot print (foot-sole replica) unless one makes a mistake of interpreting "no formation of the plantar arch" as "flat-foot". Using it in combination with roentgenography is most desirable where large amounts of data are handled.

However, roentgenograhy is not practical in terms of mechanical equipment and cost.

Therefore, the foot print (foot-sole replica) or pidoscope (equipment for photographing the foot-sole) is used at present.

2) Changes by school year in the rate of plantar arch formed and sex differences

The reason of the superiority of girls in the 3rd to 5th grade and superiority of boys in the 6th grade of elementary school to 3rd grade of the junior high school in the formation rate illustrated in Fig.2, is probably because the formation of bone presents itself earlier in girls than in boys or because boys are about 2 years behind girls in the formation of bone. As to the endogenous factor of the formation of bone, mention may be made of accelerated growth of the thyroid gland.

The cause of the formation rate that reaches a peak and then decreases in girls, may be attributable to deposition of fat in the foot arch.

This is quite possible judging from the fact that the Rohrer's index in girls tends to increase again after stabilization as seen in Fig.4.

Regarding the relationship between obesity and the plantar arch, we[7] have already begun studying it. As to the details, however, will be reported on some other occasions.

3) Difference between boys and girls and difference between the right and left in the growth of foot-sole.

(1) Difference between boys and girls and difference between the right and left in the width of foot-sole

The difference between boys and girls in the width of foot-sole becomes large particularly from the period where characteristic in both sexes become clear. This may as well be taken merely as sex differences.

But it may very considerably according to external conditions such as the natural environment and economic conditions, to which attention should be paid. Taguchi[8] has reported that the width of foot-sole is slightly larger in the left foot than in the right foot. However, present investigation shows no distinct difference in the width of foot-sole between the right and left.

(2) Factors of formation of the hallux angle, difference between boys and girls and difference between the right and left.

It is well known that the foot makes a characteristic movement in walking. That is, there is a "return" movement attendant upon the hind leg kicking period-leg playing period-floor hitting period; there is an "inward return" movement with a shift in gravity in the foreleg floor-hitting period; and, an "outward return" movement is made in the subsequent kicking period-leg playing period[9,10]. This movement is expected to put a considerable burden on the sole of the foot. The burden is heavy particularly on the rear tip of the heel, the joint of 1st metatarsus to the toe. In short, the hallux angle itself is presumed to appear when the outward return movement in the kicking period during walking imposes a heavy load on the hallux.

The difference between boys and girls in the hallux angle may be regarded as the difference between boys and girls in the amount loaded on the hallux by the outward return movement mentioned earlier.

In short, the heel of girls in the 2nd to 5th grade of the elementary school is about as wide as that of boys, but the width of the foot-sole is smaller than that of boys, and the Rohrer's index in girls is almost equal to that in boys. Therefore, the body weight per unit area on the foot-sole is presumed to be greater in girls than in boys, resulting in an increase in the load on the toe and subsequent larger expansion of the hallux angle than in boys. The difference between the right and left in the hallux angle presents itself due to using the feet each in a proper way, that is, the difference between the supporting leg and motive leg hitherto advocated by Hirasawa[11], or it is because a stronger burden is put on the supporting leg than on the motive leg.

The present investigation suggests that the hallux angle is greater in the left foot than in the right foot with the left foot serving as the supporting leg and the right foot as the motive leg in many cases.

4) 3-dimensional structure of the foot

Fig.9 illustrates the 3-dimensional structure of the foot by Mizuno[12]. As can be seen

from this figure, the 3-dimensional structure of the foot shows not only the height of the foot arch but also the width of the foot-sole and the width of the heel.

When the leveling off phenomenon of the foot-sole width and the heel width seen in Fig.5-1, and 5-2 are examined from the aspect of the 3-dimensional structure of the foot, completion of the 3-dimensional structure of the foot in the horizontal direction may be achieved once in junior high school 1-2 grade in boys and in the 6th grade or so of elementary school in girls.

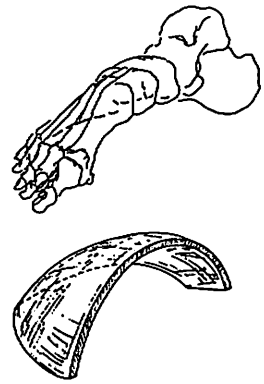

Fig 9 3-dimensional structure of the foot arch (from. Mizuno : 1984, "Foot of Man-Full of enigmas—")

Since the items of measurement in the present investigation did not include length of the foot-sole, we would like to study the longitudinal growth in the 3-dimensional structure of the foot in the future.

5) Time for the plantar arch and hallux angle to appear and walking movement

By nature, the plantar arch and hallux angle in the foot-sole appear with the growth phenomenon. These are clearly related to the walking movement. Moderate loading of movement is necessary and very important in attaining normal growth of the lower limb since the walking movement of man is completed in infancy through the period of schoolchildren.

6) Growth of the foot-sole and practical training

It is pointed out that whereas the physique of children and students have been markedly improved recently, building up of the physical strength fails to keep with it, thus resulting in various abnormalities in the body of children[13], The "building up of the physical strength", "practice of walking barefoot" or "Walk-walk movement" is attracting attention in the school education can be taken as a reflection of such an actual state of affairs.

As a result, according to reports of schools from various regions, the physical strength and formation of the plantar arch have certainly been improved.

However, what is important is that the "building up of the physical strength-building up of health" does not end up as a temporary boom but is practiced smoothly and continuously in the daily life.

It is highly possible that observation on the foot-sole provides a great deal of information which is useful in assessing health of the children and students. Therefore, we would like to study it from various angles in the future.

Acknowledgements

In closing we wish to express our thanks to teachers, children and students of elementary and junior high schools in Ie village for their cooperation.

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児童、生徒の足跡に関する研究

——発育現象における土踏まず・母趾角の出現とその意義——

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沖縄本島北部の一離島である伊江村において、全村の児童・生徒の足蹠を採取し測定・分析を行い、足蹠の発育及び土踏まず・母趾角出現の意義を検討した。

結果は次のように要約される。

1）土踏まずの形成率に男女差が見られ、小学校期は概して女子が優位にあったが、中学校期にはその差は明らかではなかった。このことは男女の成長経過の様相が異なっていることと関係しているものと思われる。
2）足幅は小学校２年生以降男子が大きく、特に小学校６年生以降は顕著であった。踵幅は中学１年生以降は男子が大きく、それ以前には男女の差は認められなかった。
3）母趾角は、男子に比べて女子が大きく、女子は小学校５年生まで拡大したが、その後横這の傾向になった。また、体位により影響をうけ、特に女子では体重との関係が大きいと思われた。
4）母趾角の大きさは男女共に左母趾角が右母趾角より大きかった。この左右差は、足の使い分け（運動脚・支持脚）により出現すると考えられる。
5）足蹠幅、母趾角の横這いは足の三次元構造の横方向への完成を示すもので、男子では　中学１年生～２年生に、女子では小学校６年生ごろにその完成が一旦なされる。