POSITION AND ALIGNMENT OF FLEX ZONES IN RUNNING SHOES

F.I. Kleindienst, R. Morrison*, M. Walther*, and X. Kälin**
Adidas-Salomon AG, Biomechanics Lab, Scheinfeld, Germany
*Department of Orthopaedic Surgery, University of Wuerzburg, Germany
**Praxisklinik Rennbahn for Orthopaedics and Sports Medicine, Muttenz, Switzerland

The right position and alignment of forefoot flexibility zones in running shoes represents a precondition to avoid overuse injuries of the foot and leg. The goal of this study was to determine foot anthropometrics, in order to set up construction guidelines for the positioning and alignment of the flex zones in running shoes. The foot anthropometrics of 471 runners were measured with a 2D scanning system under static conditions. The metatarsal-length-indices (MLI) were calculated for each ray. The calculated MLIs do not indicate the necessity for a grading pattern regarding different shoe sizes, gender dimorphism and different regions. To consider the anthropometrical variance of the MLIs it is suggested to apply flex zones instead of only flex grooves. The results suggest the application of a transversal, a longitudinal and a diagonal flex zone in running shoes.

KEY WORDS: running shoes, forefoot flexibility, foot anthropometry, construction guidelines.

INTRODUCTION: As early as 1982 Bojsen-Møller pointed out that the forefoot probably represents the part of the body which has to bear the highest mechanical stresses. Also Frederick (1987) emphasized the importance of forefoot flexibility in sport shoes and presumes that this parameter is the most frequent and strongly desired feature of runners. However, he had to realize that no scientific research had been done before. Nevertheless Frederick (1987) and Bojsen-Møller & Lamoreux (1979) as well as Bojsen-Møller (1982) point out that stiff forefoot flexibility properties could be the reason for overuse injuries. A study by Becker & Obens (1998) states that a bending movement in the midfoot region of the midsole could also lead to overuse injuries.

Therefore the main goal of the present study was to determine foot anthropometrics, in order to set up construction guidelines regarding the positioning and alignment of flex zones in running shoes. A possible dependency of gender, region and different shoe sizes (foot length) on the positioning and alignment of flex zones should also be investigated.

METHODS: The feet of 471 runners from Middle Europe (57%) and North America (43%) were measured with the Rothballer® - 2D scanning system under static conditions (Table 1). The subject group consisted of 52% female and 48% male runners. Their shoe sizes ranked from 4.5 UK up to 12.5 UK.

Table 1 Anthropometric and training data subdivided in gender and continent (mean values and standard deviations).

	Total (n = 471)	Differentiation in gender		Differentiation in continent	
		Female (n = 244)	Male (n = 227)	Middle Europe (n = 270)	North America (n = 201)
Age [years]	38.0 ± 10	37.2 ± 10	38.9 ± 11	39.7 ± 11	35.8 ± 9
Body weight [kg]	68.4 ± 12	61.4 ± 8	75.9 ± 11	69.0 ± 12	67.5 ± 12
Body height [cm]	171.3 ± 9	165.2 ± 6	177.8 ± 7	172.0 ± 9	170.3 ± 10
Training volume [km/week]	43.8 ± 24	37.5 ± 20	50.4 ± 26	45.2 ± 24	41.9 ± 24
Running experience [years]	9.0 ± 8	7.6 ± 7	10.6 ± 8	7.0 ± 7	11.7 ± 8

Preceding the scanning process a medical doctor palpated the articulation of the 1. and 5. metatarsophalangeal joint (MPJ) and than marked the anatomical rotation centers which are located proximal of the joint. Within the computerized data a line along the anterior margin of the foot (proximal of the toes) was shifted to go through the marked anatomical rotation centers of the 1. and 5. MPJ. This line goes approximately through the anatomical rotation centers of the 2., 3. and 4. MPJ. Only the left foot was analyzed (Kadanoff & Mutafov, 1967) with the

Rothballer® software (version 8.0.73). This measuring procedure was based on the recommendations of Kadanoff & Mutafov (1967, 1968). The specific characteristic of this procedure is the "oblique" measuring technique in which the pternion represents the proximal point for all measurements. Based on the absolute data (length of 1. - 5. ray; distance between pternion and 1. - 5. anatomical rotation center) the metatarsal-length-indices (MLIs) for all five rays were calculated. The MLIs (Kadanoff & Mutafov, 1968) represent the distance of the pternion to the anatomical rotation centers x 100 divided by the anthropological foot length (distance between pternion and acropodion).

RESULTS AND DISCUSSION: The comparison of the MLIs of the whole subject group (total) and the separate shoe sizes show no significant differences (Table 2). There are also no differences regarding gender, region and anthropological shoe length. The results do not show any necessity for a grading pattern regarding the position of the flex zones, especially not depending upon the shoe sizes (deviations of < 1.0%).

Table 2 Statistical data of metatarsal-length-indices of the subject group (total) and with reference to shoe size dependency (UK), data collection of the left foot.

Metatarsal-Length-Indices		Shoe size (UK)								
		4.5f (n = 26)	5.5f (n = 57)	6.5f (n = 100)	8.5f (n = 61)	6.5m (n = 15)	8.5m (n = 95)	10.5m (n = 81)	12.5m (n = 36)	total (n = 471)
1. MLI [%]	mean	73.1	73.2	73.0	73.0	73.1	72.7	72.6	72.6	**72.9**
	sd	1.1	1.2	1.2	1.2	1.3	1.0	1.1	1.5	1.2
	range	4.4	5.4	6.7	4.8	4.3	5.9	5.2	6.3	7.0
	min	71.1	70.7	69.3	70.8	70.9	70.0	70.0	69.9	69.3
	max	75.5	76.1	76.0	75.5	75.2	75.9	75.2	76.2	76.2
2. MLI [%]	Mean	74.6	74.4	74.3	74.1	74.2	73.9	73.6	73.4	**74.0**
	sd	1.1	1.3	1.3	1.4	1.7	1.1	1.3	1.6	1.3
	range	4.5	5.3	6.0	7.7	5.4	7.1	6.4	6.9	7.9
	min	72.4	72.2	70.9	70.0	71.9	70.0	69.9	70.9	69.9
	max	77.0	77.4	76.8	77.7	77.4	77.1	76.3	77.8	77.8
3. MLI [%]	mean	72.3	72.0	71.8	71.7	72.0	71.5	72.3	72.0	**71.8**
	sd	1.2	1.3	1.3	1.5	1.4	1.3	1.4	1.7	1.4
	range	4.4	5.5	5.6	7.5	4.7	7.6	6.0	6.7	8.5
	min	70.2	69.4	68.9	68.1	70.5	67.1	68.3	68.8	67.1
	max	74.7	74.9	74.5	75.5	75.2	74.7	74.3	75.5	75.5
4. MLI [%]	mean	69.3	68.9	68.9	68.6	69.2	68.5	68.2	68.4	**68.6**
	sd	1.4	1.3	1.5	1.6	1.4	1.3	1.3	1.7	1.4
	range	5.4	5.9	6.3	7.0	5.9	7.1	6.3	6.8	8.9
	min	67.0	65.5	65.7	65.2	67.2	64.2	65.3	65.6	64.2
	max	72.4	71.4	72.0	72.2	73.1	71.3	71.5	72.4	73.1
5. MLI [%]	mean	66.4	65.8	65.9	65.6	66.3	65.6	65.2	65.8	**65.7**
	sd	1.7	1.5	1.6	1.7	1.6	1.6	1.5	1.9	1.6
	range	6.5	6.4	8.8	8.9	5.6	7.7	7.7	8.3	9.5
	min	63.7	61.7	61.0	61.3	63.9	61.3	61.8	61.6	61.0
	max	70.1	68.1	69.9	70.2	70.5	69.0	69.5	69.9	70.5

However, the standard deviation as well as the range show a variance which indicates the application of flex zones instead of flex grooves only (Figure 1). The standard deviation and the range increase from the 1. MLI to the 5. MLI. This shows the highest variance especially for the 5. MLI.

Based on the finding of Jacob & Zollinger (1992), that during linear forward movements (e.g. walking and running), the 1. - 3. MPJs carry the highest load, it is suggested to apply a transversal flex axis perpendicular to the medial outline of the foot which passes the anatomical rotation center of the 1. MPJ (Figure 1).

For sport shoe manufacturing it is important to consider the thickness of the mid- and outsole unit in the forefoot region (16mm). It has an influence on the position of the transversal flex axis during push off when considering the bending angle (Figure 1). Therefore the transversal shoe flex center (69%) should be located 4% of the anthropological foot length behind the anatomical rotation center (73%; 1. MPJ). Considering the variance of the MLIs the shoe flex center zone should cover ± 1.5% (standard deviation) and the shoe flex border should be placed at ± 7% (range) of the shoe flex center (Figure 1). The shoe flex center zone should be the most flexible region of the flex zone.

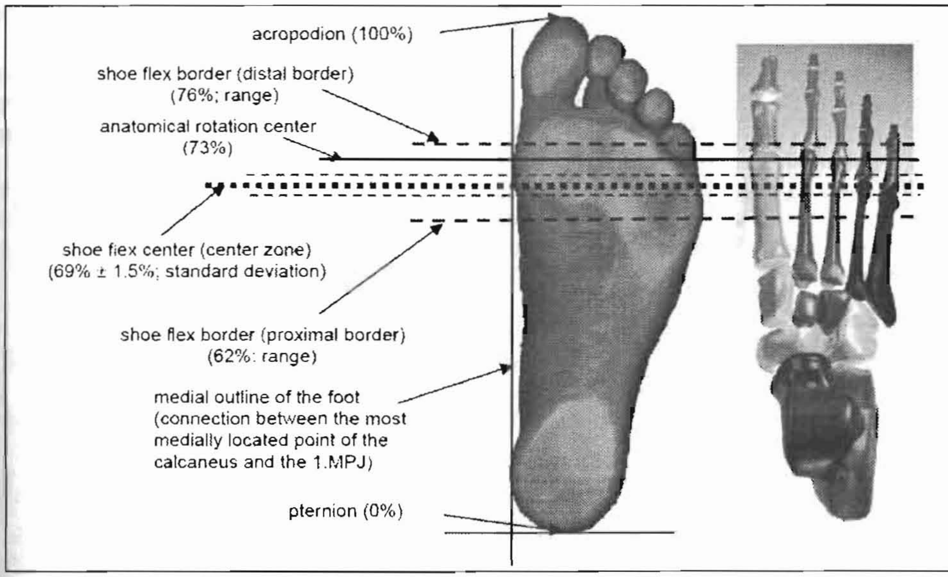
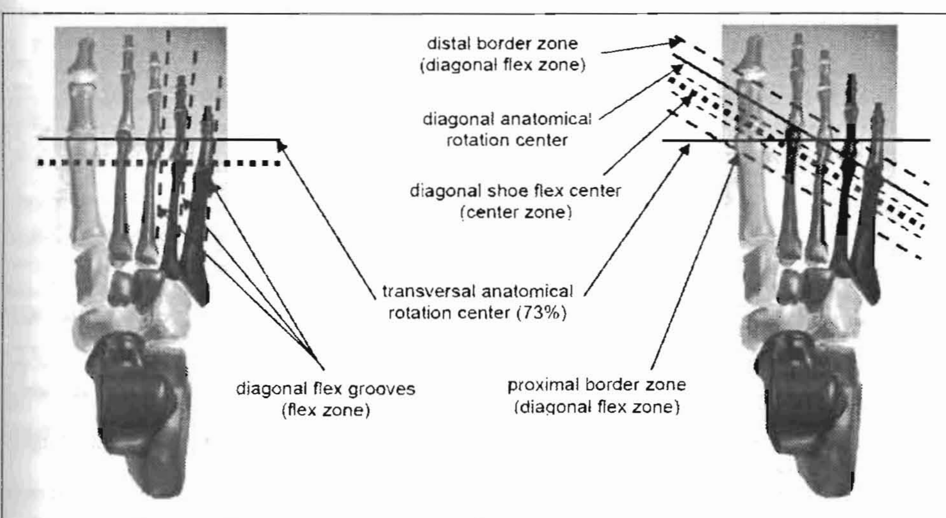


Figure 1: Construction guidelines for positioning and alignment of the transversal flex zone (not to scale).



Longitudinal flex zone	Diagonal flex zone

Figure 2: Construction guidelines for positioning and alignment of the longitudinal and diagonal (oblique) flex zone (not to scale).

To allow a natural and physiological adaptation of the forefoot to the ground a forefoot flexibility in medio-lateral direction is also required. Therefore a longitudinal flex zone placed on the lateral part of the forefoot is recommended (Figure 2; left). The application of a longitudinal flex zone also supports the torsion ability of the foot.

For push off movements towards the lateral side a diagonal flex zone is suggested (Figure 2; right). The diagonal flex axis is formed by the 3., 4. and 5. MPJ which are placed in one line starting at about 66% of the anthropological foot length underneath the 5. MPJ. The axis through these joints cuts the transversal anatomical rotation center at an angle of about 37° close to the 3. MPJ. Similar to the transversal flex zone the influence of the mid- and outsole

thickness as well as the anthropometric variance should be considered for the positioning of the diagonal flex zone (Figure 2; right).
The considerations mentioned above are primary related to the outsole, because the mechanical material properties (rubber with a high density) have an important influence on the forefoot flexibility characteristics. There are also construction possibilities which can be applied directly underneath the forefoot region (around the MPJs) on the upper side of the midsole. This could be useful in order to reduce the compression of the midsole material especially at the beginning of the push off phase (Frederick, 1987). In that context it is recommended to use the quotients calculated for the anatomical rotation centers (MLIs; Table 2) without considering the influence of the mid- and outsole thickness.

CONCLUSION: The analyzed MLIs do not indicate the necessity for a grading pattern for different shoe sizes, gender dimorphism or different regions. Considering the anthropometrical variance of the MLIs it is suggested to apply flex zones instead of only flex grooves.
During linear forward movements the 1. - 3. MPJs carry the primary load (Jacob & Zollinger, 1992), so it is recommended to use a transversal flex axis perpendicular to the medial outline of the foot which passes through the anatomical rotation center of the 1. MPJ. To place the flex zones in the right position it is important to consider the thickness of the mid- and outsole unit of the forefoot region. To ensure a smooth transition from the lateral to the medial side a longitudinal flex zone should be applied to the lateral part of the forefoot. In addition to the transversal and the longitudinal flex zone a diagonal flex zone should be placed along the 3., 4. and 5. MPJ starting at about 66% of the anthropological foot length underneath the 5. MPJ. This flex zone supports the push off movements in a lateral direction. In addition to the construction proposals for the outsole it is recommended to integrate flex zones on top of the midsole directly underneath the MPJ region without considering the influence of the mid- and outsole thickness.
The application of the suggested flex zones in running shoes by the sport shoe industry and thus for the sport shoe market can contribute to a reduction of overuse injuries. This can help to fulfill the needs of runners and will lead to an enhanced comfort perception.

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