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Bioceramic-fiber socks have more benefits than cotton-made socks in controlling bacterial load and the increase of sweat in runners

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Abstract

Background: Socks are an important element in running and can help to maintain the optimal conditions of warmth and moisture for the foot. Although socks with bioceramic fiber could be capable of having an antiperspirant and antimicrobial effect, there is little scientific evidence for such potential. Therefore, the aim of the present study was to evaluate the antimicrobial effect and the response, with regards to the foot's perspiration, of a sock with bioceramic fibers, comparing the results with those of a cotton-made control sock.

Methods: A group of 33 male runners who were about to run a half-marathon race were asked to wear the bioceramic sock (Action®) on their left foot and the control sock (Kalenji Eliofeel Warm®) on their right foot. Before the race, a microbiological culture was taken on the skin under the fifth metatarsal head, followed by a measurement of the skin moisture on five anatomical zones of the foot. These analyses were repeated at the end of the race.

Results: After the race, there were significantly fewer bacteria on bioceramic socks than on the control ($0.5 \pm 1.2 \times 10^4$ versus $1.6 \pm 2.3 \times 10^4$ colony-forming units/cm^2, respectively, $p = 0.022$). At midfoot, dorsum, and the fifth metatarsal base, there was significantly less moisture after the race on the bioceramic sock than in the control ($p = 0.011$, $p = 0.040$, $p = 0.023$, respectively).

Conclusion: Socks made of bioceramic fibers showed antiperspirant and bacteriostatic characteristics that could help to maintain the normal physiology of the skin of the foot, which could contribute to preventing dermatological diseases.

Keywords

foot, bacteria, sweat, socks, bioceramic fibers

During physical or sporting activity there is a large increase in internal heat, with sweat formation as the mechanism that tries to decrease the skin temperature (due to moisture evaporation).[1] Despite this, during running the athlete's foot is generally held inside a sock–running shoe complex with hindering perspiration.[2,3] It results in an increase in the temperature of the foot's skin,[4,5] mainly in the forefoot and midfoot.[2] This increase of temperature remains after 10 minutes of stopping running.[2]

The sock plays an important role in this process. It maintains the thermal conditions,[6] and helps to preserve a proper skin hydration of the metatarsus or between the toes.[7] Skin integrity and the presence of lesions may depend on the appropriate evacuation of the heat and sweat generated.[8] As runners are prone to foot lesions,[9] a good hydration status of the foot and

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the inhibition of bacterial growth could prevent the appearance of lesions and infections.[10,11] On the one hand, excessive dryness of the foot leads to the appearance of hyperkeratosis,[12] and on the other hand, a high level of skin sweating could result in more blisters.[8] Also, Lacroix et al.[10] established that 31% of a sample of marathon runners had *tinea pedis* infection[10] due to the occlusive sock–running shoes. So, improving the characteristics of socks might help to reduce the prevalence of these foot lesions.

Today, textiles made of new fibers are available, such as bioceramics (with different inorganic materials, such as silicon, calcium, aluminum, magnesium, sodium, zirconium silicate, and titanium oxides), which have biological properties. Bioceramic fibers have the effect of absorbing the infrared radiation of the body and returning it in the form of long-length infrared radiation, which can lead to an increase of vasodilation.[13] This effect has been associated with different benefits in patients, such as pain reduction, prevention of inflammatory processes, or improvement of circulation.[13–15] As for the possible effect of the bioceramic fibers in thermoregulation, only one study has assessed runners.[16] In this study, decreased temperatures were observed by the use of t-shirts made from bioceramic fibers, suggesting that the increase in circulation could have an improvement on thermoregulation. However, little is known of these potential antiperspirant or antimicrobiological effects. Although other characteristics such as yarn or fabric structure could influence the thermal, moisture, and anti-frictional effects of socks,[17–19] it is necessary to assess the effects of bioceramic socks during exercise. Depending on the effect, these socks might be indicated for all kinds of environments, being more positive for cold or even warm temperatures.

The hypothesis of the present study is that bioceramic socks lessen humidity and reduce bacterial growth when compared with a control, cotton-made sock. So, the aim of the present study is therefore to evaluate the effect on bacterial growth and perspiration of the foot of a sock with bioceramic fibers compared with a control, cotton-made sock.

Material and methods

The sample size in the present study was estimated using the software Epidat 3.1, in which the level of confidence was 95% and statistical power 90%. A study of the variance was made with the first 10 participants, finding that standard deviation differences between pre- and post-race (S^2) was 1.79 CFU (colony-forming units). In controls, there are differences in the same participant from 0.99 CFU,[20] so the aim is to find a precision of $\pm$ 0.99 CFU. The result of the formula showed that sample size for the present study consisted of a minimum of 31 participants. To avoid the loss of sample (estimated in 6%, due to possible injuries or not arrival to the finish line), two more runners were recruited.

Therefore, the sample consisted of 33 male athletes, mean age 38.7 ± 8.4 years, mean weight 70.3 ± 9.8 kg, and mean height 171.9 ± 8.1 cm. Males were recruited for being more numerous in races of this type.

Participants gave their verbal and signed, written, and informed consent to participation. The Declaration of Helsinki is a set of ethical principles regarding human experimentation developed for the medical community by the World Medical Association (WMA). It is widely regarded as the cornerstone document on human research ethics. The clinical trial was registered with the code ACTRN12615000370505.

Inclusion and exclusion criteria

For inclusion in the study, the participant had to be capable of running for at least 120 minutes at a pace of between 5 and 6.5 minutes per kilometer. Participants were excluded if their feet were not free of skin lesions (bacterial or fungal infections, or painful hyperkeratosis), or if they did not meet the necessary conditions of hygiene.

All of the participants in the sample were habitual runners, with best times in a half-marathon competition of 95 ± 9 min (1 h 35 min). Samples were collected in May 2015 at a half-marathon event (21 km).

Pre-race measurements

The athletes were requested to wash their feet before the race in order to have the same hygienic conditions. They were given two socks, one of bioceramic-type fibers (Figure 1, Action®, Ekynox Wear Granada, Spain; composed of 90% polyester impregnated in the form of the filament yarn with 1% of bioceramics, 5% polyamide, 5% elastane), and the other a control sample with the same color, thickness, and design (Figure 1, Kalenji Eliofeel Warm®, Decathlon, France; composed of 79% cotton, 17% polyester, 3% elastane, 1% polyamide). Figure 2 shows the deposits of inorganic material over the polyester filaments.

As the result of a random choice, the left foot was dressed in a bioceramic sock, while the control sock was used for the right foot. The participants were familiarized with the socks by wearing them during a five-minute walk, prior to the start of the race.

Microbiological study

Sampling. After the five minutes of adaptation, socks were removed and swabs were taken from the plantar

Figure 1. Control and bioceramic socks

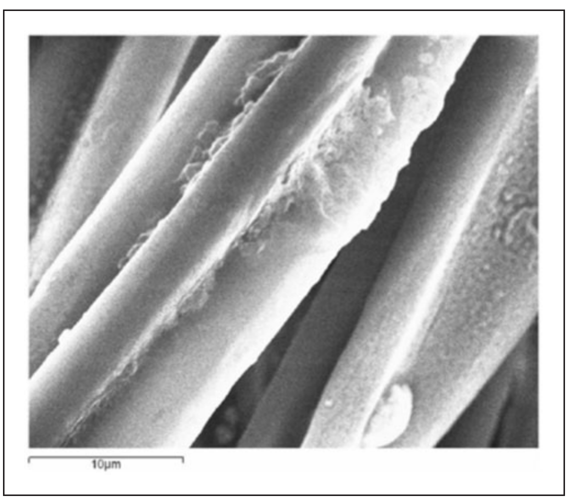

Figure 2. Detail of inorganic deposits over the fibers

surface of each foot's fifth metatarsal head by a 10-second application of sterile swabs (Deltalab SL, Spain) with Amies Viscosa as the transport medium. Although this medium allows microorganisms to have 3 days of viability, their recovery is improved if they are cultured within the first 24 hours.

Sample analysis. Samples were sent to the laboratory for microbiological study. Analyses were made within the first 6 hours. The protocol was as follows: swabs were re-suspended for 10 seconds in 2 ml of 0.9% saline solution. Using a Drigalski inoculation loop, 20 μl aliquots of the solution were plated in triplicate onto 5% blood agar (a highly nutritious isolation medium which facilitates growth of most bacteria, irrespective of their metabolism). After 24–48 hours of incubation at 35°C, the colonies that had grown on each plate were counted, using a bright light base and dividing the plate into quadrants to facilitate counting. The bacterial colonies were counted visually twice by two authors, and the average of the four measurements were used for the statistical analysis.

The data were expressed as the mean of the three measurements for each sample in terms of CFU per 20 μl volume. These results were then transformed to CFU/cm^2, taking the area of the sample collected by the swab as 0.75 cm^2.[21] The formula for this transformation is the following: if the mean CFU for a sample was X CFU per 20 μl of solution, then this corresponded to (X·100) CFU for the 20 ml total solution, and hence (X·100)/0.75 CFU/cm^2 in terms of area of skin (in the tables, for clarity, the results will be presented with a 10^4 exponent).

Analysis of foot moisture. The foot's hydration was measured using a Hydrosensor moisture meter (Microcaya S.L., Bilbao, Spain), of dimensions 18 cm × 12 cm × 3 cm, and 0.25 kg weight. The ambient temperature and relative moisture at the time of measurement were 20 ± 0.5°C and 50 ± 5%, respectively. These measurements were taken immediately after removing their socks and after the microbial swab culture (so as not to interfere with the bacterial load), resting the sensor on the skin of five anatomical zones (heel, midfoot, base of the fifth metatarsal, head of the first metatarsal, and central zone of the dorsum). The results were displayed on a row of diodes showing values of 1–10.

Post-race measurements

Following the completion of the two pre-race samples, the participants ran the half-marathon race. At the finish, smears were again collected, and foot moisture measurements were made following the same protocols as pre-race. One year later (in the same half-marathon event), a subsample of 15 participants (that were within the 33 initial), that ran the event again was collected, to repeat the tests (wearing the same bioceramic socks than in the initial race) and to assess how continuous washing cycles affect the theoretical benefits of the sock fibers. In this case, no control socks were used, and the comparison were conducted between pre- and post-race CFU and the increase of sweat in the bioceramic socks.

A descriptive statistical analysis (mean ± SD) was made of the pre-race moisture data and bacterial colonies. Then the increments were calculated from pre-race to post-race in colony counts (ΔCFU = colonies-post – colonies-pre) and in moisture for each of the five areas analyzed (ΔH = H-post – H-pre). These increments were compared between the two feet using a Student's *t*-test for paired samples. Correlations between bacterial growths with anthropometric variables and race time were conducted by means of bivariate Pearson's correlations. All statistical analyses were done using the SPSS version 15.0 software package, setting a significance level of 5% ($p < 0.05$).

Results

Bacterial load

Before the race, the amount of bacteria levels generated on the sample socks' surface was measured as 131 and 96 CFU for the tested bioceramic and control socks, respectively. On the post-race condition, there were 171 CFU on the bioceramic sock and 215 CFU on the control, corresponding, therefore, to increments of 40 and 119 CFU, respectively. Figure 3 represents one of the cases, with a bacterial growth near the means described. The most common bacteria found were, in decreasing order, *Staphylococcus lentus*, *Staph. lugdunensis*, *Staph. aureus*, *Streptococcus viridans*, and *Strep. porcinus*. All are from normal bacterial flora, but have the potential to provoke infections when the skin's normal acid barrier is damaged, mainly *Staph. aureus*.

The bioceramic sock placed on the left foot presented higher CFU pre-race than the control sock on the right foot, which could be attributed to the laterality of athletes (active hand doing the washing). Expressing bacterial load in terms of CFU/cm^2, the results (Table 1) showed that after completion of the race, there had grown fewer bacteria on the bioceramic sock ($0.5 \pm 1.2 \times 10^4$ CFU/cm^2) than on the control sock ($1.6 \pm 2.3 \times 10^4$ CFU/cm^2), the difference being statistically significant ($p = 0.022$, Table 2).

Regarding the correlation analysis, only the age presented a moderate negative correlation between the amounts of generated bacteria load on the runners'

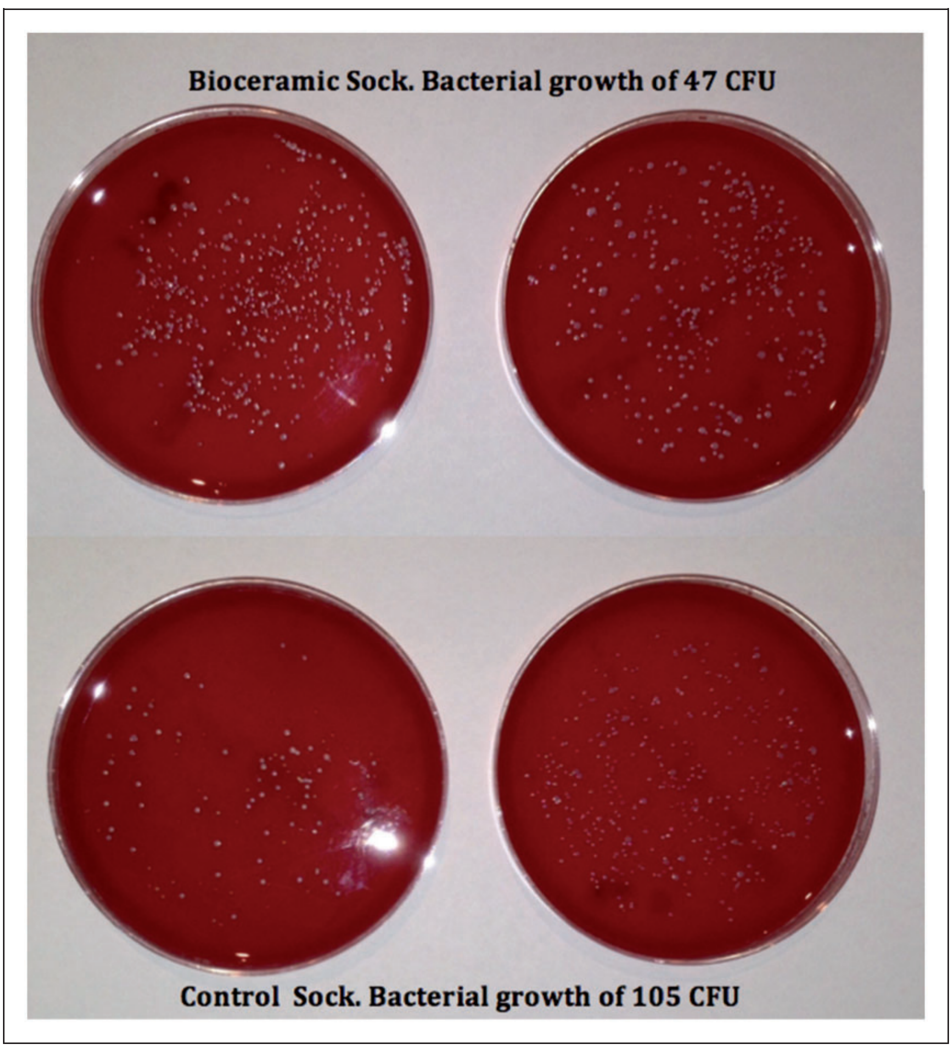

Figure 3. Bacterial growth in one of the cases

bioceramic sock ($r = -0.549$, $p = 0.001$, Table 3), although no other significant correlation was found. This means that the older athletes are expected to have less bacterial growth on their socks.

Moisture

The pre-race moisture data of the two feet in the five zones analyzed are given in Table 4. The highest values corresponded to the dorsum, with a mean score of 4.6 on the control sock and 4.1 on the bioceramic sock. None of the analyzed foot areas presented significant differences between the control and bioceramic socks ($p > 0.05$ in all cases, Table 4).

After the race, the area that showed the greatest increase in moisture was the dorsum, with 3.3 points for the control sock and 2.4 for the bioceramic sock. There were statistically significant lower increases in moisture on the bioceramic sock than on the control one for three of the five zones measured: midfoot, fifth metatarsal base, and dorsum (Table 5).

Effect of the washing cycles

One year later, in the same race, and with multiple washing cycles affecting the bioceramic socks, the following results were observed. In terms of bacterial growth, an increment of 52 CFU was observed, and there was an increase in moisture of 1 (heel), 0.9 (midfoot), 0.8 (5th metatarsal base), 1.2 (1st metatarsal head) and 2.5 (dorsum) points after the race.

Discussion

This study was designed to assess the effect of wearing bioceramic socks on properties provided by the runners, because these socks are marketed as mitigating the effects of the harsh conditions of heat and moisture that arise during running. Being enclosed in a dark, warm, and humid environment inside a sock and a shoe, a runner's feet are subjected to conditions that may lead to increased sweating and bacterial load, and therefore to the possible occurrence of dermatological afflictions.[9,22]

Table 1. Descriptive statistics of the colony-forming units ($CFU \times 10^4/cm^2$)

	Pre-race Mean ± SD	Post-race Mean ± SD
$CFU/cm^2 \times 10^4$ Bioceramic sock	1. 8 ± 2.4	2.3 ± 2.6
$CFU/cm^2 \times 10^4$ Control sock	1.3 ± 1.2	2.9 ± 2.6

Table 2. Comparison of bacterial growth (Δ) for the two feet

	Delta (post–pre)	*p* value
$CFU/cm^2 \times 10^4$ Bioceramic sock	0.5 ± 1.2	**0.022**
$CFU/cm^2 \times 10^4$ Control sock	1.6 ± 2.3	

Table 4. Moisture pre-race in the five zones and differences between feet

Zone	Bioceramic sock Mean ± SD	Control sock Mean ± SD	*p* value
Heel	3.3 ± 1.2	3.6 ± 1.8	0.634
Midfoot	3.9 ± 1.7	3.9 ± 1.5	0.875
Base of 5th metatarsal	3.3 ± 1.3	3.7 ± 1.7	0.347
1st metatarsal head	3.6 ± 1.7	3.9 ± 1.8	0.291
Dorsum	4.1 ± 1.4	4.6 ± 1.8	0.178

Table 5. Moisture increase (Δ = Post – Pre) in the five zones and differences between feet

Δ humidity zone	Bioceramic sock Mean ± SD	Control sock Mean ± SD	*p* value
Heel	0.8 ± 1.1	1.4 ± 1.7	0.144
Midfoot	0.8 ± 1.3	1.5 ± 1.1	**0.011**
Base of 5th metatarsal	0.7 ± 0.8	1.2 ± 1.1	**0.040**
1st metatarsal head	1.2 ± 1.3	1.7 ± 1.2	0.062
Dorsum	2.4 ± 1.5	3.3 ± 2.1	**0.023**

Table 3. Correlations of bacterial growth (Δ) with anthropometric variables and race time

		Age	Weight	Height	Gender	Race time
Δ Bioceramic sock	*r* coefficient	**-0.549**	0.011	0.116	-0.078	-0.176
	p value	**0.001**	0.950	0.521	0.666	0.423
Δ Control sock	*r* coefficient	-0.034	-0.220	-0.335	0.132	0.254
	p value	0.849	0.219	0.057	0.465	0.242

Results confirmed our hypothesis, showing that socks with bioceramic fibers have beneficial effects, with lower bacterial growth as measured on the plantar aspect of the fifth metatarsal head (Table 2) and smaller increases in sweating in three areas (midfoot, base of the fifth metatarsal, and dorsum; Table 5) when compared with cotton-made control socks. The dorsum of the foot, which pre-race had a higher level of moisture than the other four zones measured, was the zone where the bioceramic sock led to the greatest evacuation of sweat. These results can be explained because cotton-made socks absorb moisture from the skin better than polyester fibers, which expels the excess of sweat.[23] However, this retention of sweat may impair comfort. Besides, this increase of water in the foot's skin provides a rich environment for bacterial growth that could explain the higher increase of bacterial growth. In a high activity exercise, as running, the main mechanism heat and moisture loss is evaporation,[24] although the shoes are an obstacle for the transport of this evaporated sweat to the outside.

Regarding bacterial growth, there are three phases. The first is adaptation, in which the bacteria adapt to the environment, with slow growth.[25,26] The second is characterized by exponential growth of the cells. Under appropriate conditions, a Gram-positive bacterium can divide every 20–30 minutes, and a Gram-positive every 15–20 minutes.[27] Finally, there is a stationary phase: the result of depletion of the nutrients in the medium.[25,26] In our case, we found the bacterial growth to be in the exponential phase, since, in the approximately 95 minutes (on average) of the race, the bacterial load in the control sock tripled, while there was much slower growth in the bioceramic sock (Tables 1 and 2). Hence, one can say that this model of bioceramic sock (Action®) would have a bacteriostatic effect, that has also been observed in other kind of socks, mainly in metallic-based fibers, such as nanosilver[28] and copper oxide.[29]

The use of bioceramic socks could thus prevent the occurrence of bacterial infections or superinfections of the plantar skin, an area susceptible to lesions during running.[22] This bacteriostatic effect has also been observed with the use of running shoe insoles made of porous viscoelastic polyurethane, with this material inhibiting the growth of bacteria, especially of pseudomonas, micrococci, diphtheroids, and staphylococci.[30] In this sense, the bacterial control provided by the type of sock studied in the present work supports their use for everyday training.

The persistent decrease of moisture in the bioceramic sock has the coadjuvant beneficial effect of being capable of reducing the occurrence of lesions such as blisters, since these are generated by skin friction, which is greater when the skin is more moist.[31] Blisters should not be regarded as a minor problem, because besides being painful, like other plantar lesions, such as calluses,[32] they can lead to biomechanical alteration of the running pattern.[33] The bioceramic sock, made from single terry jersey, generates less friction than the control sock with a high single jersey structure,[34] so could help to avoid blister formation. In addition, polyester itself has shown to lead to a lower incidence of blistering of the foot.[35] Indeed, the lower percentage of polyester fibers and higher percentage of cotton in the control sock could lead to more humidity retention than bioceramic socks.

Leung et al.[16] stated that the coadjutant effect of vasodilation of the bioceramics leads to better thermoregulation. So, this bioceramic materials integrated in polyester fabric socks may thus improve the sweat management. In some garments, the textile base is immersed in bioceramic fibers. This can reduce their useful life because the bioceramic coating can be lost with wear. In the Action® socks, however, the bioceramic fibers are integrated into the polyester yarn before weaving. This ensures better resistance to multiple washing–drying–using cycles, as in the first half-marathon, the bacterial growth after the race was 40 CFU in the bioceramic sock, and one year later, the growth was 52 CFU (far from the 119 CFU of the control socks). This confirms the bacteriostatic effect of bioceramic fibers over a long period. Indeed, considering the season, weather of the place and month (May) of the race as relatively cold, (mean of 15.6°C), polyester based socks seems to be the best choice for the moisture management.[36]

Bioceramic socks could be recommended as routine training wear for runners, especially those prone to hyperhidrosis or the appearance of skin lesions. But one also finds diverse potential future applications of this technology in socks. Another population susceptible to foot lesions and increased risk of infection is that of diabetics. Since the bacterial flora of the human skin can play an important part in causing or modifying skin disorders, and the feet of diabetic patients have augmented populations of *Staph. aureus*,[37] the use of socks with certain bacteriostatic properties may reduce the risk of infection of superficial lesions.[38]

One limitation of the study is that athletes ran with their own running shoes (not standardized). This could affect breathability, but in this case, thermal and other characteristics were the same, since one sock was placed on each foot, and running shoes were the same for both, so these did not bias the results. In addition, the number of washing–drying cycles were not controlled. So, the long-term results obtained could be less reliable. The obtained result that older athletes have less bacterial growth is a surprising result and needs more attention in further studies to clarify the possible effect of age in bacterial load.

In summary, we found the following chain of events happens in order to achieve the current results: (1) bioceramic socks allow better sweat evaporation than control socks; (2) drier feet (bioceramic socks) are less inclined to the bacterial growth, that is partially inhibited; (3) more moist feet (control sock) are a favorable environment for bacterial growth.

Conclusions

Socks with bioceramic fibers have bacteriostatic properties, controlling bacterial growth during running, which may help prevent infection. In addition, they manage the generation of moisture more effectively than cotton-based socks. Both effects provide benefits to runners with respect to the integrity of skin tissue and potentially reducing the prevalence of lesions, such as painful blisters, that are associated with an excess of moisture and temperature.

Declaration of conflicting interests

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