Moisture Permeability of the Total Surface Bearing Prosthetic Socket with a Silicone Liner: Is It Superior to the Patella-Tendon Bearing Prosthetic Socket?

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Abstract: The purpose of this study was to examine the moisture permeability properties of materials used for total surface bearing (TSB) socket with a silicone liner, a combination of Silicone Suction Socket or Icelandic Roll-On Silicone Socket (ICEROSS®) and an acrylic plastic sheet (Degaplast®), patella-tendon bearing (PTB) socket, a combination of Pe-Lite® and Degaplast, and wooden socket made of poplar. Moisture permeability of the socket materials was measured as the diminution of water in a container after 12 hours in a climatic chamber. Eight containers with their open, top side were uncovered (no material) or sealed with one of the socket materials; the experiment was repeated four times. One-way analysis of variance followed by Bonferroni’s test was applied to examine the differences in moisture permeability. Moisture permeability levels were as follows: no material, 85.9±1.3g; poplar, 4.3±0.4g; Silicone Suction Socket, 1.1±0.2g; ICEROSS, 1.0±0.2g; Pe-Lite, 0.8±0.1g; 3S+Degaplast, 0.8±0.1g; ICEROSS+Degaplast, 0.8±0.2g; and Pe-Lite+Degaplast, 0.8±0.1g. There were significant differences between the uncovered container and the others, and between poplar and the others (P<0.05). We concluded that the TSB socket with a silicone liner is not superior to the PTB socket with regard to moisture permeability, and that it is necessary to develop a new prosthetic socket that allows heat release and drainage of sweat.

Key words: total surface bearing, socket, patella-tendon bearing, perspiration, heat loss.

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Introduction

In recent years, patella-tendon bearing (PTB) prosthetic sockets [1], which were the worldwide standard for trans-tibial amputees, are being frequently replaced with total surface
bearing (TSB) prosthetic sockets [2, 3]. An ordinary TSB socket consists of a rigid outer socket, viscoelastic prefabricated or molded silicone inner socket, and connective equipment [3, 4]. The TSB socket with a silicone liner has certain recognized advantages: (1) comfort during stance phase, (2) ease of movement during swing phase, and (3) reduced piston movement. Although the TSB socket with a silicone liner is generally regarded as superior to the PTB socket, the TSB socket may have stump and socket hygiene problems, such as itch, perspiration, eruption, and odor [5]. Fillauer et al. described a gradual diminution in perspiration after applying the TSB socket [3], and Cluitmans et al. also noticed a marked decrease in skin problems after several weeks or months [6]. However, Hachisuka et al. reported that 39 (47%) out of 83 TSB socket users complained of excessive perspiration within the socket [7].

Before examining the perspiration problem of the TSB socket users, we have to know what factors are related with perspiration, e.g. moisture permeability from the stump skin to the outside of the hard socket, heat conduction, convection, and radiation of the TSB socket with a silicone liner, peripheral circulation in the stump, and direct and indirect effects on sweat secretion [8]. Although several factors may be involved in the heat loss mechanism of the TSB socket user, we first intended to examine moisture permeability of the materials used for TSB, PTB, and wooden sockets as an index of heat loss by evaporation in this study, and to reveal whether the TSB socket with a silicone liner is superior to the standard PTB socket with regard to moisture permeability.

**Materials and Methods**

Moisture permeability of materials used for the TSB socket with a silicone liner, a combination of Silicone Suction Socket [3] or Icelandic Roll-On Silicone Socket (ICEROSS®) [4] and an acrylic plastic sheet (Degaplast®), PTB socket, a combination of polyethylene foam rubber (Pe-Lite®) and Degaplast, and wooden socket made of poplar was measured as the diminution of weight of a rectangular cubic container containing distilled water, of which the open, top side was covered and sealed by different sheets composed of the materials used for the sockets. The container was fabricated with a 5-mm thick polypropylene sheet; the top side was open, 10.0 by 20.0 cm; the bottom side was 9.0 by 18.5 cm; 10.0 cm in depth; a 3-cm wide lip was attached around the top side (Fig. 1). First, 1,000 ml of distilled water was poured into the container; a sheet of one

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A) 3-S part A, part B, oil, and inhibitor; Fillauer Inc., 2710 Amnicola Highway, Chattanooga, TN, U.S.A.
B) IRS-20; Össur, Grjóðháls 5, 110 Reykjavik, Iceland
C) Teufel, Necksstrees 189-191, 7000 Stuttgart, Germany
D) Pe-Lite; Fillauer Inc., 2710 Amnicola Highway, Chattanooga, TN, U.S.A.; A-20
E) Sekisui Chemical Co., 2-4-4, Nishitenma, Kita-ku, Osaka, Japan
F) BL2200S; Shimazu, 1 Nishinokyo Kuwabara-cho, Nakagyo-ku, Kyoto, Japan
of the materials was placed over the top side of the container and a frame with the same shape as the lip of the container, which was cut from a 5-mm thick polypropylene sheet, was set on the sheet. The container was then covered and sealed by the sheet, gripping the frame and the lip firmly in 30 small vises. To prevent a leak from a minute gap between the sheet and the lip of the container, a 2-mm-thick pad made of natural rubber having the same shape as the lip of the container was inserted between the sheet and the lip, and the joints between the sheet and pad and between the pad and lip were plugged with liquid paraffin. The sealed container including distilled water was weighed in an electronic balance with a minimum display of 0.01g at the start of the experiment and retained in a climatic chamber where temperature (37°C) and humidity (70%) simulated conditions inside the socket when worn [9]. The container was weighed again after 12 hours. The measurements were repeated on four different days.

Socket materials measured were as follows: (1) no material, (2) poplar board, (3) Silicone Suction Socket (an inner socket of the TSB), (4) ICEROSS (an inner socket of the TSB), (5) Pe-Lite (a liner of the PTB), (6) a combination of Silicone Suction Socket and Degaplast (inner and outer sockets of the TSB), (7) a combination of ICEROSS and Degaplast (inner and outer sockets of the TSB), (8) a combination of Pe-Lite and Degaplast (a liner and outer socket of the PTB). The poplar board was 10-mm thick, sliced from a wooden block, scraped and ground to make a wooden quadrilateral socket for a trans-femoral amputee. The thickness of the board was determined as being as thick as the standard wall of the wooden quadrilateral socket. An amputee, particularly prone

![Diagram](image_url)

**Fig. 1.** Cross section of the rectangular cubic container.

The rectangular cubic container and frame were made of a 5-mm thick polypropylene sheet, and the pad was made of a 2-mm thick natural rubber sheet. A sheet of one of the materials was placed between the frame and the lip of the container, and the container containing distilled water was sealed by gripping the frame and the lip firmly in 30 small vises. The joints between the sheet and pad and between the pad and lip were plugged with liquid paraffin (→).
to perspiration, regards a wooden socket as being the most comfortable option. The Silicone Suction Socket was a 2-mm thick silicone sheet containing three layers of the nylon stockinet inside, and was fabricated by an experienced prosthetist based on Fillauer’s report [3]. The ICEROSS was a 3-mm thick silicone sheet, which was cut away from a commercially available prefabricated silicone cone. Pe-Lite was a 5-mm thick polyethylene foam rubber sheet, which is used as a material for a liner inserted into the PTB socket. Degaplast was a 4-mm thick acrylic plastic sheet compounded of the same mixture as the hard socket, because the typical outer hard sockets of the TSB and PTB sockets are usually fabricated with this acrylic plastic.

Moisture permeability was obtained by subtracting the weight of the container containing distilled water after 12 hours from the initial weight. Data were presented as the mean±standard deviation, one-way analysis of variance followed by Bonferroni’s test was applied to examine differences among materials, and differences with a P-value of less than 0.05 were regarded as significant.

Results

When the container was not sealed, 85.9±1.3g of distilled water evaporated and diffused from the container, while 4.3±0.4g of distilled water diffused through the poplar board. When the container was sealed with a sheet of one of the socket materials, its weight diminution was slight: Silicone Suction Socket, 1.1±0.2g; ICEROSS, 1.0±0.2g; Pe-Lite, 0.8±0.1g. When Degaplast was combined with each of the three materials, the weight diminutions in the three combinations became the same: Silicone Suction Socket + Degaplast, 0.8±0.1g; ICEROSS + Degaplast, 0.8±0.2g; Pe-Lite + Degaplast, 0.8±0.1g (Fig. 2). There were significant differences between having no material and the others, and between poplar and the others (one-way ANOVA followed by Bonferroni’s test, P<0.05), but the differences were not significant in the case of sheets of Silicone Suction Socket, ICEROSS, and Pe-Lite with or without Degaplast (P>0.05).

Discussion

When an amputee wears a prosthesis, heat is generated in the deep-set organs, especially the skeletal muscles during walking, and is conducted to the skin by the blood, which is controlled by the degree of vasoconstriction of the arterioles and arteriovenous anastomoses that supply blood to the venous plexus of the skin [10]. In accordance with the mechanism of heat loss in the human body [8], heat loss from the stump skin seems to be based on the same mechanism: evaporation, conduction, convection and radiation. Sweat evaporation takes heat from the human body surface. Perspiration depends on activation of the sweat secretion process and the degree of acclimatization of the sweating
mechanism, and evaporation from the stump skin through the prosthetic socket may be
affected by the moisture permeability of the socket materials as much as by the rate of
perspiration. Conduction is direct heat loss from the stump skin to the socket. Convection
is a heat loss via the circulating fluid around the stump skin. Because there is no space
between the stump skin and the silicone liner, convection may be ignored in the TSB
socket. However, if an amputee wearing the PTB socket has excessive piston movement
of the socket during walking, forced convection has to be considered as a possible
mechanism of heat loss. Radiation is heat loss in the form of infrared heat rays [10],
releasing heat to the face of a wall apart from the stump skin. This type of heat loss
may be also ignored when using the TSB socket, because there is no space inside the
socket.

To deal with the stump and socket hygiene problems of the TSB socket with a silicone
liner, i.e. itch, perspiration, eruption, and odor, it is necessary to examine the heat loss
mechanisms from the stump skin through the prosthetic socket. First of all, we compared
moisture permeability of materials used for the TSB, PTB, and wooden sockets. Although

![Graph](image-url)

**Fig. 2.** Moisture permeability.
Moisture permeability, which was obtained by subtracting the weight of the container plus the remaining
distilled water after 12 hours from the initial weight of the container containing 1,000ml of distilled
water, was expressed as mean±standard deviation. Poplar: a 10-mm thick board[^1], 3S: Silicone
Suction Socket[^2], ICEROSS: Icelandic Roll-On Silicone Socket[^3], Pe-Lite: polyethylene foam rubber[^4],
3S+DP: the combination of 3S and Degaplast (an acrylic plastic sheet[^5]), ICEROSS+DP: the com-
bination of ICEROSS and Degaplast, Pe-Lite+DP: the combination of Pe-Lite and Degaplast. *and**
vs. the other 7 materials: one-way ANOVA followed by Bonferroni's test, \( P<0.05 \).
several methods to measure moist permeability have been reported [11-14], the method adopted in this study [12] was to measure the weight change of an object. The reasons for this were as follows: the method was the simplest; predicted values were very low; relative comparison was adequate.

Our experiment was carried out in a climatic chamber at our university to simulate the inside environment of the socket. Although much attention was paid to prevent moisture leaks from the sealed face between the container and the material being tested, a few leaks might have occurred. Because the procedure of the measurements was theoretically acceptable, and fluctuations of the measurements were considerably low, such leaks seem to have been rare and, if any did occur, their occurrence would have been almost equal in all the trials. Consequently, comparison of the moisture permeability in this study may be permitted.

Pe-Lite, on its own, and the three combinations ofsilicones or Pe-Lite with Degaplast had very low and equal moisture permeability levels, indicating that they had actually no permeability, if unavoidable moisture leak was excluded. Moisture permeability of Silicone Suction Socket and ICEROSS was more than that of Pe-Lite and the three combinations, although not significant. However, the extent of the differences of moisture permeability may not be subjectively obvious in daily use. Because the combination of Silicone Suction Socket or ICEROSS and Degaplast, which are constituents of the TSB socket, has as low a moisture permeability level as the combination of Pe-Lite and Degaplast, which are constituents of the PTB socket, the TSB socket with a silicone liner is not superior to the PTB socket with regard to evaporation of sweat from the stump skin through the prosthetic socket. Our result explains why 47% of the TSB socket users complained of excessive perspiration within the socket.

If a prosthetic socket for a trans-tibial amputee is made of wood, the socket may be more comfortable, especially for an amputee prone to sweating. At present, a wooden TSB socket for a trans-tibial amputee is not frequently recommended, because of the difficulty of carving and modification. In order to develop a new prosthetic socket that allows heat release and drainage of perspiration from the stump skin to the outside of the socket, further research is required on other factors relating to heat loss of the TSB socket, i.e. conduction, and sympathetic nerves activities and pressure-sweating reflex [5, 10, 15].

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References

シリコンライナーを用いた全表面荷重式義足ソケットの通湿性—膝蓋腱荷重式ソケットよりも優れているか？—

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要 旨： 下腿切断者が使用する義足ソケットの素材の通湿特性を明らかにする目的で、プラスチック製容器に蒸留水を1000ml入れ、測定する素材で蓋をして密封し、人工気象室に12時間放置してその重量変化を通湿性の指標とした。重量変化は、蓋無し85.9±1.3g: ポプラ4.3±0.4g: Silicone Suction Socket 1.1±0.2g: Icelandic Roll-On Silicone Socket (ICEROSS®), 1.0±0.2g: Pe-Lite®, 0.8±0.1g: Silicone Suction Socket + Degaplast®, 0.8±0.1g: ICEROSS + Degaplast, 0.8±0.2g: and Pe-Lite + Degaplast, 0.8±0.1gであり、木製ソケット素材のポプラが有意に通湿性に優れていた（一元配置分散分析、Bonferroni検定）。しかし、その他のシリコン素材、熱硬化性樹脂、その組み合わせはいずれも通湿性に乏しく、少なくともシリコン素材を使用する全表面荷重式ソケット（Silicone Suction Socket または ICEROSS と Degaplast の組み合わせ）が膝蓋腱荷重式ソケット（Pe-Lite と Degaplast の組み合わせ）よりも通湿性に優れているとはいえないかった。

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