Journal of Literature and Art Studies, ISSN 2159-5836
February 2013, Vol. 3, No. 2, 125-136

Physiological Analysis for Universal Design of Public Seat Under Diverse Conditions*

Takeshi Kitamura, Koichiro Sato, Yoshiyuki Matsuoka
Keio University, Yokohama, Japan

Takeo Kato
Tokai University, Tokyo, Japan

Public vehicle seats are used under diverse conditions, therefore, the design of these seats is desired to be universal design. In the past study, seat swing function used in public vehicle seats, and it was optimized from the mechanical aspect under diverse conditions. Seat swing function is the function to prevent hip-sliding force, which causes sitting uncomfortable feeling. Recent study clarified that the reduction of blood flow in the legs causes physiological dysfunction, which is one of the causes of Long Flight Thrombosis, and the social issue. Thus, in the design of seat swing function, it is necessary to consider not only mechanical aspects but also physiological aspects. For the universal design of seat swing function considering the physiological aspect (blood flow), the influence of blood flow on seat swing function in diverse conditions was analyzed. The method of this study was measuring blood flow and body pressure distribution on seat cushion of seat swing function under diverse conditions. From the analysis, it was indicated that it was necessary to reduce the compressive force behind the knees of the user conditions; the short physique and the high weight physique in standard sitting posture, for the universal design of seat swing function to prevent reduction of blood flow in the legs.

Keywords: universal design, diverse conditions, seat, blood flow

Introduction

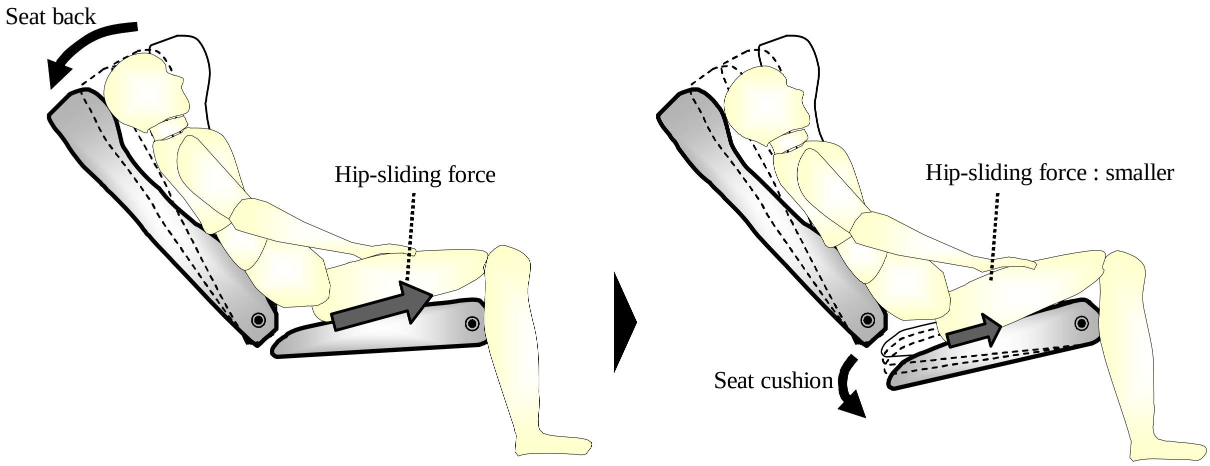
Background

Because the general population utilizes public seats, such as railway vehicle seats, they are used in diverse conditions, and are influenced by many factors related to humans, objects, and the environment. Although railway vehicle seats are used under varied conditions, conventional seat designs typically consider only average conditions, which include the average physique and standard sitting posture. Thus, conventional design solutions are often poorly evaluated under specific conditions. Therefore, for robust evaluations, public vehicle seats should be universally designed by considering diverse conditions.

* **Acknowledgements:** This work is supported in part by a Grant in Aid for the Global COE (Center of Excellence) for "Center for Education and Research of Symbiotic, Safe, and Secure System Design" from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

Takeshi Kitamura, master, Graduate School of Science and Technology, Keio University.
Takeo Kato, Ph.D., Department of Mechanical Engineering, Tokai University.
Koichiro Sato, Ph.D., Faculty of Science and Technology, Keio University.
Yoshiyuki Matsuoka, Ph.D., Faculty of Science and Technology, Keio University.

A previous study has clarified that hip-sliding force causes an uncomfortable sitting posture, and optimized the seat swing function used in public vehicle seats based on mechanical aspects to prevent this force (see Figure 1) (Matsuoka & Morita, 2001; Niwano & Matsuoka, 1998). The seat swing function is a function to prevent hip-sliding force by adjusting the C.A. (cushion angle) when a user adjusts the B.A. (back angle) to assume comfortable sitting posture. In the previous study, human-seat models were constructed, and simulations with the constructed models yielded a hip-sliding prevention curve to depict the relationship between the back angle and cushion angle to prevent hip-sliding force. Then a seat swing function was designed using the hip-sliding prevention curve, and the validity of the design solution was evaluated by a sensory experiment. Although the seat swing function was optimized from mechanical aspects, physiological aspects were not assessed.



Step 1 : A user adjusts the seat back to assume comfort sitting posture.
(Hip-sliding force generates in the situation.)

Step 2 : Seat swing function prevents hip sliding force by adjusting seat cushion.
(Hip-sliding force is smaller than Step 1.)

Figure 1. Seat swing function and hip-sliding force.

Recently, it has been reported that sitting on a seat for a long time can cause deep vein thrombosis (Kuipers, Schreijer, & Cannegieter, 2007; Hitos, M. Cannon, & S. Cannon, 2007; Becker, Salim, & Kelman, 2006; Paganin, Bourde, & Yvin, 2003), and preventing thrombosis is a social issue. One plausible cause is reduced blood flow in the lower limbs. Thus, seat swing function designs must consider not only mechanical aspects, but also physiological aspects, especially the influence of the seat swing function on blood flow in the lower limbs. Employing the seat swing function changes the human-seat compression, and previous studies have clarified that the distribution of body pressure affects blood flow (Sato & Nakamura, 2007; Kawa, Morooka, & Kitamura, 1995; Tanaka, Yoshida, & Hirata, 1999). Therefore, it is likely that changing the human-seat compression with the seat swing function affects blood flow. Hence, this study evaluates the influence of the seat swing function on blood flow using the relationship between human-seat compression and blood flow.

Objective and Method of This Study

This study aims to clarify the influence of the seat swing function, which was optimized with regard to hip-sliding force, on blood flow under diverse conditions. Additionally, this study will provide useful knowledge to design a universal seat swing function with respect to physiological aspects.

The first part of the experiment measures blood flow for various physiques and sitting postures to determine the influence of the seat swing function on blood flow under diverse conditions. Herein the results of a pervious study were used to determine the seat angles (Matsuoka & Morita, 2001; Niwano & Matsuoka, 1998).

The second part measures body pressure distribution using the same conditions as the first part as well as anatomical analysis to elucidate the influence of the seat swing function on blood flow under diverse conditions, because previous studies have clarified that the distribution of body pressure affects blood flow (Sato & Nakamura, 2007; Kawa, Morooka, & Kitamura, 1995; Tanaka, Yoshida, & Hirata, 1999; Shibata & Hirata, 1995).

Finally, from the analysis, which is based on the relationship between blood flow and compressive force under diverse conditions, useful knowledge to design a universal seat function with respect to physiological aspects is clarified.

Experiment to Measure Blood Flow

Experimental Conditions

Subjects. To evaluate passengers with various physiques, three different levels of height and weight were considered (*Reference Manual Anthropometry in Ergonomic Designing*, 1996). Of the nine possible height and weight combinations, two were statistically rare, and eliminated based on the robust design method, the mean value *m*, and $\pm\sqrt{3/2}\sigma$ (see Tables 1-2).

Table 1

Physique Level of Examinees

		Height		
		$m-\sqrt{3/2}\sigma$	m : Average	$m+\sqrt{3/2}\sigma$
Weight	$m-\sqrt{3/2}\sigma$	Physique 1 (Short physique)	Physique 6 (Corpulent physiqu	-
	m : Average	Physique 4 (Corpulent physiqu	Physique 2 (Average physique	Physique 5 (Slim physique)
	$m+\sqrt{3/2}\sigma$	-	Physique 7 (Slim physique)	Physique 3 (Tall physique)

Table 2

Height and Weight of Each Physique Level

	$m-\sqrt{3/2}\sigma$	m : Average	$m+\sqrt{3/2}\sigma$
Height (cm)	163.7	171.4	179.6
Weight (kg)	53.2	63.3	73.4

Sitting postures. Two types of sitting postures, the standard sitting and hip-sliding sitting, have been previously reported for passengers in public vehicles (Saito & Wakabayashi, 1997). In the standard sitting posture, a passenger sits such that the buttocks are firmly on the seat cushion and the waist comes in contact with the seat back. In contrast, in the hip-sliding sitting posture, a passenger sits with the buttocks slid forward and the pelvis rotated such that the waist does not come into contact with the seat back. Herein three types of sitting postures are considered as diverse conditions, the standard sitting posture and hip-sliding sitting postures where the buttocks is slid 100 mm and 200 mm from the standard sitting posture (see Figure 2).

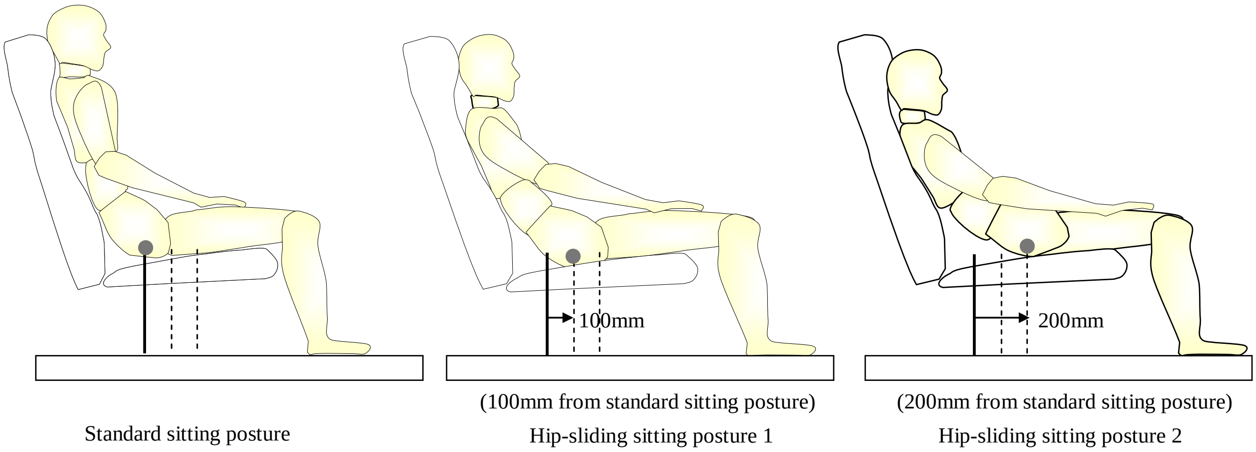


Figure 2. Sitting postures.

Seat angle (B.A. and C.A.). The seat angle in the experiment was determined from the hip-sliding prevention curve (Matsuoka & Morita, 2001; Niwano & Matsuoka, 1998), which is the design solution of the seat swing function optimized in the previous study (see Figure 3). This curve shows the B.A. is maximized at 40 degrees, which is where the hip-sliding force is maximized and the seat swing function is most effective. Thus, B.A. is fixed at 40 degrees, the C.A.s are determined. The standard is C.A. = 8 degrees, which is the same condition as a seat not equipped with a seat swing function. Because the hip-sliding force is the same as C.A. = 8 degrees, but in the opposite direction, C.A. = 32 degrees is also selected. In addition, C.A. = 24 degrees and C.A. = 20 degrees are used, because in the previous optimization C.A. = 24 degrees is the design solution considering average conditions, and C.A. = 20 degrees is the design solution considering diverse conditions.

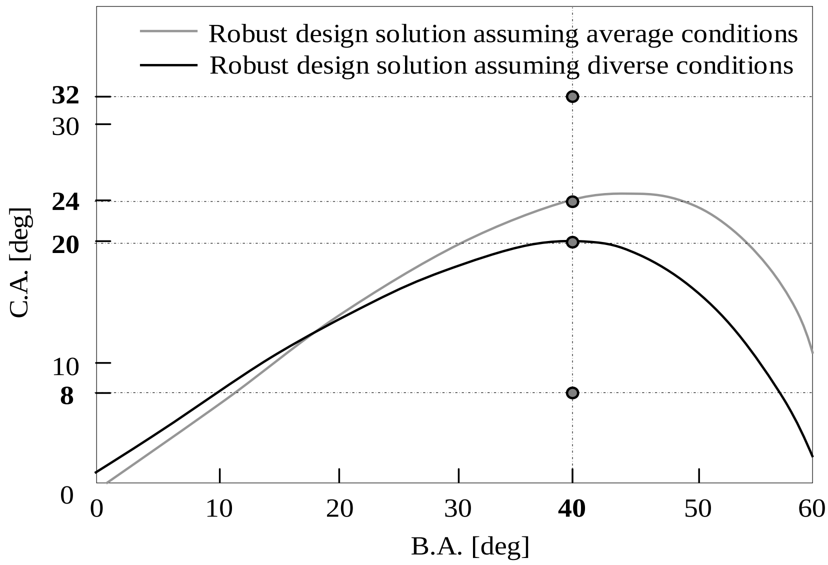


Figure 3. Hip-sliding prevention curve.

Environment and measurement region. Before measuring blood flow, subjects rested quietly in sitting posture for one hour to prevent the influence of the subjects' condition, posture, meal, and temperature on blood flow. Measurements began three hours after the last meal. The temperature in the room was 26 ± 1°C.

Previous studies have reported that mechanical compression on the body influences blood flow on the feet more than that of the pressed body (Sato & Nakamura, 2007; Kawa, Morooka, & Kitamura, 1995; Tanaka, Yoshida, & Hirata, 1999; Shibata & Hirata, 1995). Hence, sesamoid bones were used as the measuring point, because blood flow through these bones is easy to measure and is not influenced by autonomic nerves (see Figure 4).

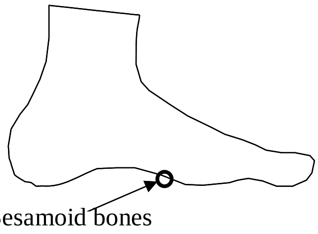


Figure 4. The measuring region of blood flow.

Experimental Procedure

Seat angle measurements. Seat angles were measured using a spirit level based on the method provided by Japan Railway.

Blood flow measurements. Blood flow was measured for three minutes with a laser blood flow meter (Kubli, Waeber, Dalle-Ave, & Feihl, 2000). There were 12 experimental variations per person: three sitting postures (standard sitting posture, 100 mm hip-sliding sitting posture, and 200 mm hip-sliding sitting posture) and four C.A. variations (C.A. = 8, 20, 24, and 32 degrees).

Results and Discussion

Previous studies have reported that blood flow is influenced by mechanical force on a human body (Sato & Nakamura, 2007; Kawa, Morooka, & Kitamura, 1995; Tanaka, Yoshida, & Hirata, 1999; Shibata & Hirata, 1995), and have indicated that human-seat compressive force on a seat cushion with a seat swing function influences blood flow. Thus, to clarify the influence of seat swing function on blood flow, the human-seat force was measured.

Human-Seat Force on the Seat Swing Function

Estimated human-seat force. The human-seat force has two directions: perpendicular to the cushion surface, i.e., compressive force, and parallel to cushion surface, i.e., the hip-sliding force. The hip-sliding force and compressive force were estimated using human-seat models as well as by the equation constructed in the previous study (Matsuoka & Morita, 2001; Niwano & Matsuoka, 1998) (see Table 3).

Table 3

Hip-Sliding Force and Compressive Force Estimated by Simulation

		Standard sitting posture		Hip-sliding sitting posture 1		Hip-sliding sitting posture 2	
		Hip-sliding force (N)	Compressive force (N)	Hip-sliding force (N)	Compressive force (N)	Hip-sliding force (N)	Compressive force (N)
C.A. [deg]	8	59.5	213.2	35.1	234.6	80.1	195.0
	20	15.0	181.6	10.4	204.9	51.8	147.0
	24	1.2	169.2	26.6	193.0	40.7	130.0
	32	35.4	142.5	60.9	167.0	14.1	95.0

Influence of the human-seat force on blood flow. The influences of the hip-sliding and compressive forces on blood flow were analyzed through multiple regression analysis where the objective variable was blood flow and the explanatory variables were the hip-sliding force and compressive force. The multiple correlation coefficient for the compressive force was 0.92, where the standard partial regressions of the hip-sliding and compressive forces were -0.07 and -0.96 ($p < 0.01$), respectively. Thus, compressive force impacts blood flow more than the hip-sliding force.

Body pressure distribution measurements. Body pressure distribution on the seat cushion was measured by analyzing the influence of compressive force on blood flow. The conditions used to measure body pressure were the same as those used to measure blood flow. That is, diverse conditions were considered: seven physiques and three sitting postures. The conditions used to measure body pressure distribution were as follows:

(1) Seat area to measure body pressure distribution. The seat cushion was the measurement area;

(2) Method to measure the body pressure distribution. The measuring equipment included a sensor mat, called I-SCAN produced by NITTA. It consisted of an aggregate of 10-square-millimeter sensors. After calibration, body pressure distribution was measured using the same experimental order as that used to measure blood flow.

Influence of the Seat Swing Function on Blood Flow in Diverse Conditions

Relationship between C.A. and blood flow. Figures 5-6 show the results of the blood flow and the body pressure measurement for all subjects by C.A., respectively. The blood flow results are shown as the average of blood flow for all subjects over three minutes. The result of the body pressure distribution shows the body pressure curves, which estimate the total body pressure by compressing a 10-square-millimeter sensor at the cross section of the seat cushion. For all participants, when C.A. increased, blood flow decreased. Additionally, the body pressure distribution at each C.A. indicated that two parts of the body had striking changes in body pressure: the ischial tuberosity and the thigh, confirming that compressive forces in these two body regions influence blood flow.

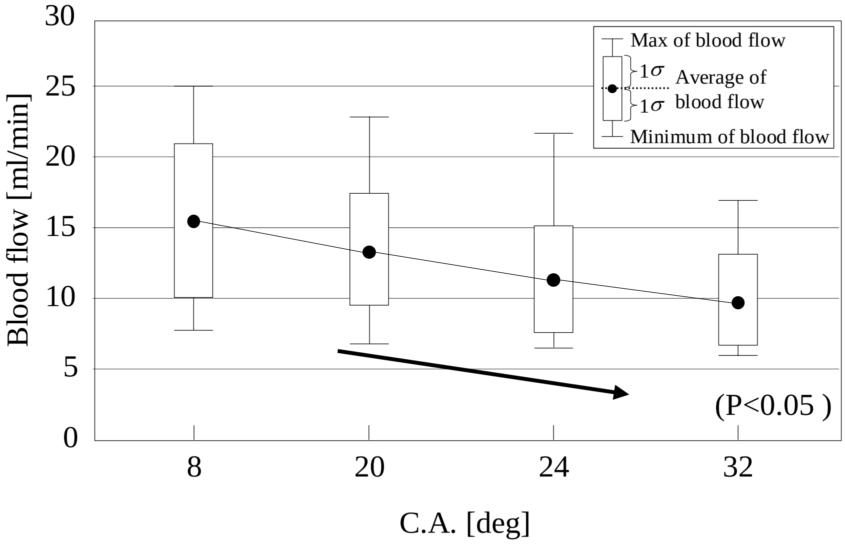


Figure 5. Blood flow on changing C.A..

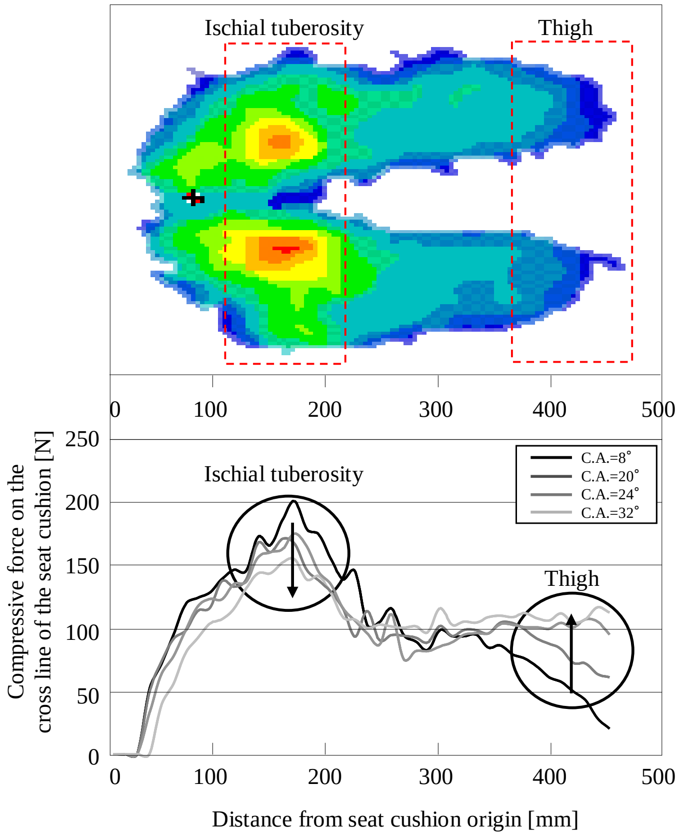


Figure 6. Body pressure curves on changing C.A..

Thus, correlation analyses between blood flow and compressive force at these two parts of the body were performed. Similar to previous studies (Sato & Nakamura, 2007; Kawa, Morooka, & Kitamura, 1995; Tanaka, Yoshida, & Hirata, 1999; Shibata & Hirata, 1995), mechanical compressive force to the body affected blood flow. High correlation levels were observed between the compressive force at the ischial tuberosity and the thigh and blood flow. The correlation coefficients at the ischial tuberosity with the standard sitting posture, hip-sliding posture 1, and hip-sliding posture 2 were 0.79, 0.63, and 0.71 (p < 0.05), respectively, whereas the correlation coefficients at the thigh with the standard sitting posture, hip-sliding posture 1, and hip-sliding posture 2 were -0.85, -0.88, and -0.96 (p < 0.01), respectively. Hence, the decreased blood flow with an increased C.A. led to a decrease in the compressive force at the ischial tuberosity, but an increase in compressive force at the thigh. Therefore, an increase in the compressive force at the thigh decreases blood flow.

Relationship between sitting postures and blood flow. Figures 7-8 show results of the blood flow measurement and body pressure distribution for each sitting posture, respectively. Blood flow increased for hip-sliding postures, but the result of body pressure distribution measurement showed that the compressive force increased. The reason for this was analyzed from an anatomical viewpoint. The popliteal vein and small saphenous vein in the lower limbs are particularly close to the skin's surface just behind the knees (see Figure 9). Thus, these veins are probably very susceptible to compressive force. Because the knees in the hip-sliding sitting posture are away from the edge of the seat cushion compared to the standard sitting posture, there is less compressive force on the popliteal vein and small saphenous vein relative to the standard sitting posture (see Figure 2). Therefore, blood flow increases in the hip-sliding sitting posture due to a decrease in the compressive force on the popliteal vein and small saphenous vein.

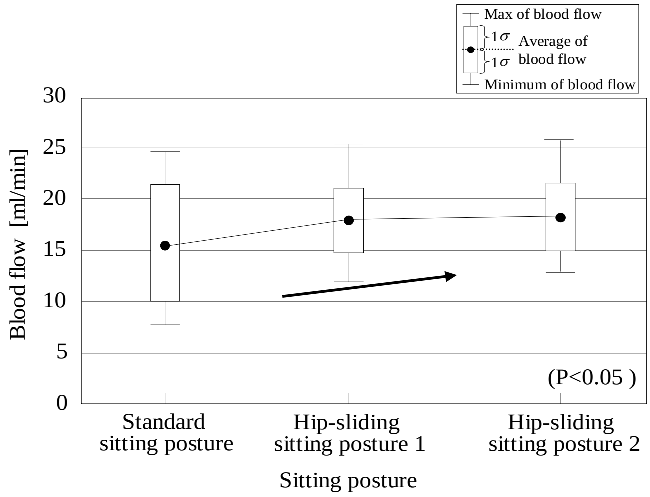


Figure 7. Blood flow on each sitting posture.

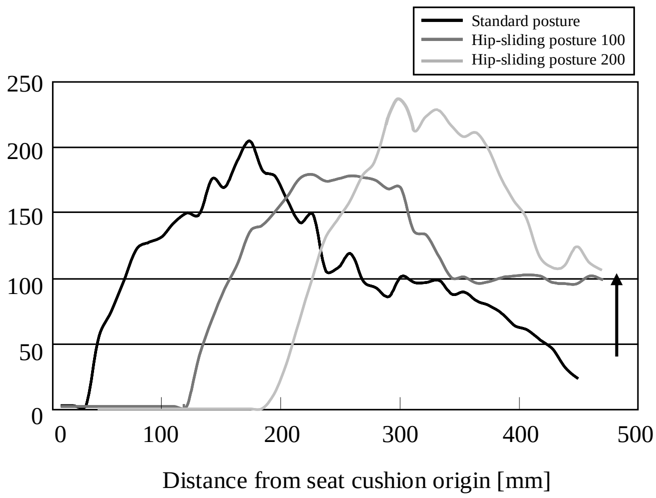


Figure 8. Body pressure curves on each sitting posture.

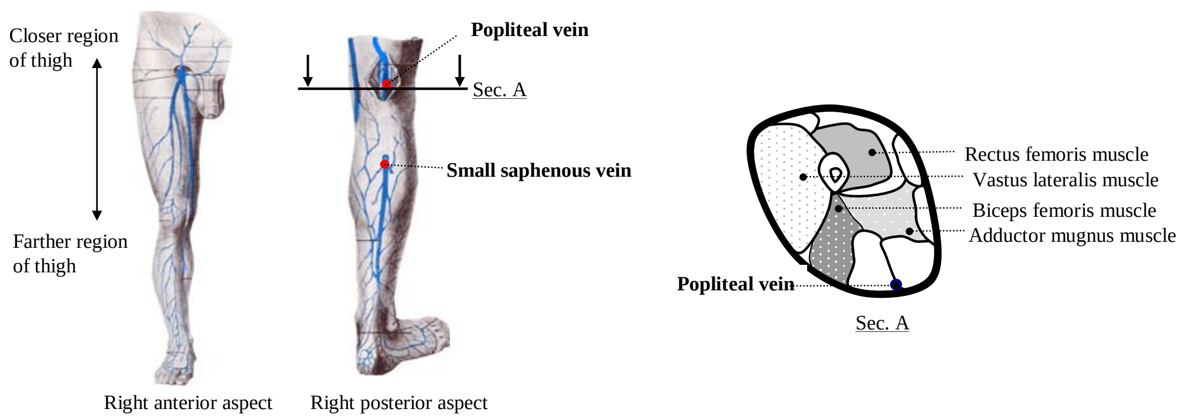


Figure 9. Superficial vein in the lower limbs.

Relationship between physiques and blood flow. ***Relationship between height and blood flow.*** To analyze the influence of height on blood flow, we focused on the body pressure of the thigh, and the compressive force ratio (R_p) on the thigh, which is calculated below (see Formula 1). The thigh was defined as the 100 mm range from the edge of seat cushion.

$R_p = P_t/P_T$ Formula (1)
R_p: Compressive force ratio from the edge of seat cushion on the thigh;
P_T: Compressive force from the entire seat cushion on the thigh;
P_t: Compressive force for the 100 mm area from the edge of seat cushion on the thigh.

Figure 10 shows the analysis result of the compressive force ratio for each C.A. on the height of each examinee. The compressive force ratios at C.A. = 8, 20, and 24 degrees, which are common inclines, for short physiques were larger than these on tall physiques. Thus, the blood volume decreased more for short physiques than tall physiques, implying that shorter users have more compressive force on the thigh in the standard sitting posture. This observation is reasonable, because shorter physiques have shorter lower limbs than tall physiques, and for the foot to be in contact with the floor the knee angle of short physiques at these angles is more acute. Thus, compared to tall physiques, short physiques have more compressive force at the C.A. = 8 degrees, which leads to a larger decrease in volume of blood flow, and shorter users have a greater risk of deep vein thrombosis.

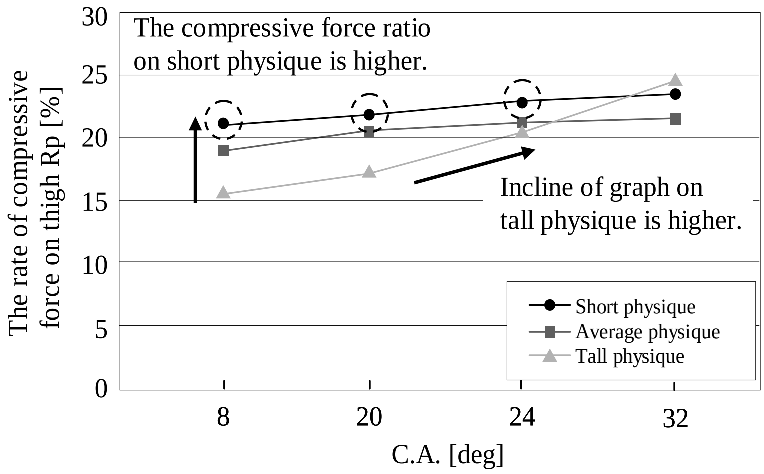


Figure 10. Compressive force ratio on the thigh of each height examinee.

For C.A. = 8 degrees, the knee angle of tall physiques is larger than that of short physiques, whereas for C.A. = 32 degrees, the knee angle of tall physiques is the same as short physiques. Therefore, taller physiques experience a greater incline, and the decrease in blood volume is larger as the C.A. increases. Hence, the increasing volume of compressive force on tall physiques is greater than that on other physiques. However, if highly used frequencies (C.A. = 8, 20, and 24 degrees) are considered, then the compressive force on short physiques is larger than that on tall physiques. Therefore, it is necessary to reduce the compressive force on short physiques compared to the tall physiques for a universally designed seat swing function.

Relationship between body type and blood flow. Figures 11-12 show the results of the blood flow measurement and body pressure distribution for each body type, respectively. Blood flow of corpulent physiques was less than that of slim physiques for each C.A. and body pressure distribution on the thigh of corpulent physiques was larger than that of slim physiques.

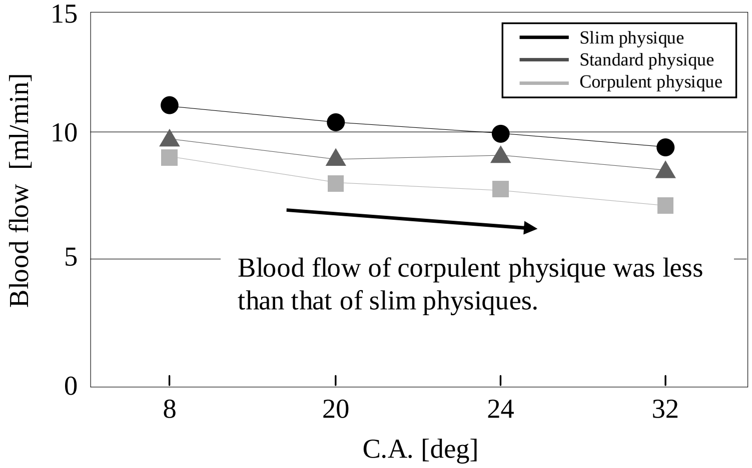


Figure 11. Blood flow on each body type.

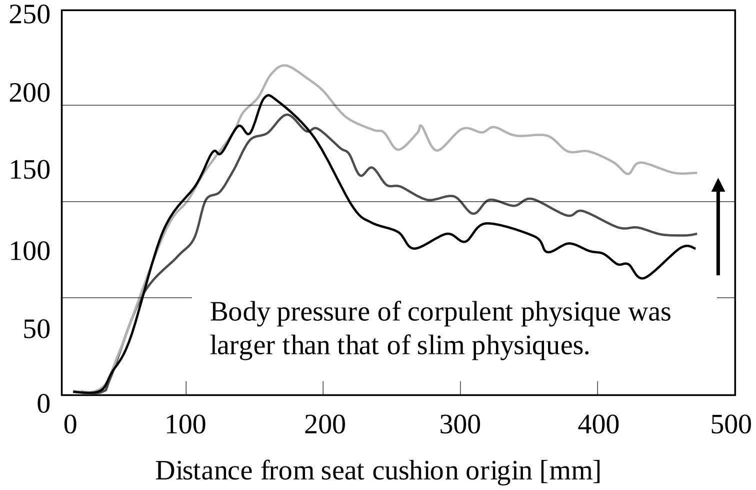


Figure 12. Body pressure curves on each body type.

From the analysis based on an anatomical viewpoint, one reason that the compressive force on the veins, particularly the popliteal vein and small saphenous vein, in the lower limbs of corpulent physiques is larger than that of slim physiques is due to increased weight. Therefore, the risk of deep vein thrombosis on corpulent physiques is higher than that on slim physiques.

Useful Knowledge for a Universally Designed Seat Swing Function Considering Physiological Aspects

From the analysis of influence of the seat swing function on blood flow in diverse conditions, useful knowledge to design a universal seat swing function with respect to physiological aspects was clarified.

First, from the analysis of relationship between sitting postures and blood flow, it was clarified that compressive force on the veins, especially the popliteal vein and small saphenous vein in the lower limbs, must be decreased to prevent reduced blood flow when creating a universally designed seat swing function.

Second, from the analysis of relationship between physiques and blood flow, it was clarified that reducing the compressive force is crucial for short physiques and corpulent physiques, because the compressive force on the veins of these physiques is higher than other physiques (see Figure 13).

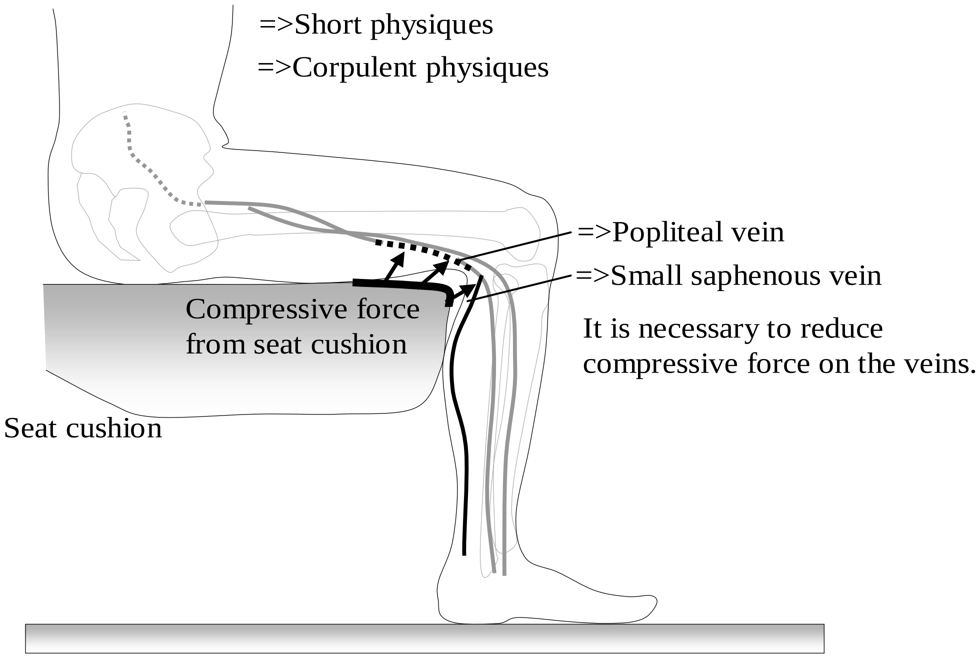


Figure 13. Useful knowledge for universal design of seat swing function.

Conclusions

Physique influences blood flow; short and corpulent physiques have a greater risk of deep vein thrombosis as they were more impacted than other physiques. Second, compared to the standard sitting posture, assuming a hip-sliding posture increases the blood flow. Furthermore, analysis from an anatomical viewpoint clarifies that compressive force on the popliteal vein and small saphenous vein in the lower limbs influences the reduction in blood flow. Hence, to design a universal seat swing function, it is important to reduce the compressive force on the veins of short physiques and corpulent physiques to prevent decreased blood flow.

References

Becker, N. G., Salim, A., & Kelman, C. W. (2006). Air travel and the risk of deep vein thrombosis. *Australian and New Zealand Journal of Public Health, 30*(1), 5-9.

Hitos, K., Cannon, M., & Cannon, S. (2007). Effect of leg exercise on popliteal venous blood flow during prolonged immobility of seated subjects implications for prevention of travel-related deep vein thrombosis. *Journal of Thrombosis and Haemostasis, 5*(9), 1890-1895.

Kawa, H., Morooka, H., & Kitamura, K. (1995). The influence of localized pressure of lower body on the amount of skin blood flow, an assumption to establish a design guide to support panty hose. *Journal of the Japan Research Association for Textile End-Uses, 36*(7), 491-494.

Kubli, S., Waeber, B., Dalle-Ave, A., & Feihl, F. (2000). Reproducibility of laser Doppler imaging of skin blood flow as a tool to assess endothelial function. *Journal of Cardiovascular Pharmacology, 36*(5), 640-648.

Kuipers, S., Schreijer, A. J. M., & Cannegieter, S. C. (2007). Travel and venous thrombosis a systematic review. *Journal of Internal Medicine, 262*(6), 65-72.

Matsuoka, Y., & Morita, A. (2001). Design of swing-seat function using simulation of hip-sliding force. *The Science of Design, 47*(5), 615-634.

Niwano, A., & Matsuoka, Y. (1998). Robust design method for variety of ba (pp. 93-100). *Third Asia Design Conference*.

Paganin, F., Bourde, A., & Yvin, J. L. (2003). Venous thromboembolism in passengers following a 12-h flight, a case-control study. *Aviation Space and Environmental Medicine, 74*(12), 1277-1281.

Reference manual anthropometry in ergonomic designing. (1996). Industrial Products Research Institute Agency of Industrial Science and Technology.

Saito, M., & Wakabayashi, H. (1997). Development and verification of railway seat for long term sitting (pp. 405-408). *JSME Centennial Grand Congress—The 6th Transportation and Logistics Conference*.

Sato, H., & Nakamura, M. (2007). Relationship between numbness and peripheral blood flow in seiza position (sitting on ones heels) of healthy subjects. *Yamanashi Nursing Journal, 6*(1), 53-57.

Shibata, Y., & Hirata, K. (1995). The physiological effects of shoes' pressure on the feet (Section 2) the effects of posture change and exercise on peripheral circulation of the feet. *Report of the Consumer Science Research Institute of Hyogo Prefecture, 10,* 150-156.

Tanaka, K., Yoshida, M., & Hirata, K. (1999). Effect of the peripheral pressure at groin region immediately after the wear of girdle on the rate of blood flow in the skin at the bottom of feet and surface humidity on the skin. *Journal of the Japan Research Association for Textile End-Uses, 40*(3), 46-53.