doi: 10.1111/j.1475-097X.2011.01044.x

Effects of walking with blood flow restriction on limb venous compliance in elderly subjects

Haruko Iida[1], Toshiaki Nakajima[1], Miwa Kurano[1], Tomohiro Yasuda[1], Mikako Sakamaki[2], Yoshiaki Sato[3], Tatsuya Yamasoba[4] and Takashi Abe[2]

[1]*Department of Ischemic Circulatory Physiology, KAATSU Training, Graduate School of Medicine, The University of Tokyo, Tokyo,* [2]*Department of Human and Engineered Environmental Studies, The University of Tokyo, Chiba, Japan,* [3]*KAATSU International University, Rajagiriya, Sri Lanka and* [4]*Department of Otolaryngology and Head and Neck Surgery, Faculty of Medicine, The University of Tokyo, Tokyo, Japan*

Correspondence
Toshiaki Nakajima, M.D., Department of Ischemic Circulatory Physiology, KAATSU Training, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
E-mail: hiida-tky@umin.ac.jp

Accepted for publication
Received 11 November 2010;
accepted 23 June 2011

Key words
blood flow restriction; elder female subjects; endurance exercise; plethysmography; venous compliance

Summary

Venous compliance declines with age and improves with chronic endurance exercise. KAATSU, an exercise combined with blood flow restriction (BFR), is a unique training method for promoting muscle hypertrophy and strength gains by using low-intensity resistance exercises or walking. This method also induces pooling of venous blood in the legs. Therefore, we hypothesized that slow walking with BFR may affect limb venous compliance and examined the influence of 6 weeks of walking with BFR on venous compliance in older women. Sixteen women aged 59–78 years were partially randomized into either a slow walking with BFR group ($n = 9$, BFR walk group) or a non-exercising control group ($n = 7$, control group). The BFR walk group performed 20-min treadmill slow walking (67 m min^{-1}), 5 days per week for 6 weeks. Before (pre) and after (post) those 6 weeks, venous properties were assessed using strain gauge venous occlusion plethysmography. After 6 weeks, leg venous compliance increased significantly in the BFR walk group (pre: 0·0518 ± 0·0084, post: 0·0619 ± 0·0150 ml 100 ml^{-1} mmHg^{-1}, $P<0·05$), and maximal venous outflow (MVO) at 80 mmHg also increased significantly after the BFR walk group trained for 6 weeks (pre: 55·3 ± 15·6, post: 67·1 ± 18·9 ml 100 ml^{-1} min^{-1}, $P<0·01$), but no significant differences were observed in venous compliance and MVO in the control group. In addition, there was no significant change in arm compliance in the BFR walk group. In conclusion, this study provides the first evidence that 6 weeks of walking exercise with BFR may improve limb venous compliance in untrained elder female subjects.

Introduction

The venous system of the human body can be looked at as a large blood reservoir that contains more than 70% of the total blood volume at rest and plays an important role in maintaining cardiovascular homeostasis. Small changes in peripheral blood volume can greatly affect cardiac filling pressure and, subsequently, cardiac output. Therefore, appropriate regulation of venous blood volume is essential, especially during various physiological conditions such as haemorrhage and orthostatic load (Olsen *et al.*, 2000).

Ageing is one of the most important factors that influence leg venous compliance. According to Monahan *et al.* (2001), calf venous compliance was about 40% lower in elderly subjects. Olsen & Länne (1998), Fu *et al.* (2000), Tsutsui *et al.* (2002) and Hernandez & Franke (2005) also demonstrated similar results. The mechanisms of this decline in venous compliance through ageing are not yet obvious; however, structural alterations, namely venous wall thickening and an increase in the collagen/elastin ratio in venous walls, which are also observed in arterial walls, may cause an age-related decline in venous compliance (Pareira *et al.*, 1953). On the other hand, functional alterations such as vasomotor tone and nitric oxide synthesis are also thought to cause age-related decline in venous compliance. Several studies have revealed that venous compliance is improved by habitual endurance exercise, and leg venous compliance is decreased in sedentary subjects compared with endurance-trained men (Louisy *et al.*, 1997; Wecht *et al.*, 2000; Monahan *et al.*, 2001; Hernandez & Franke, 2005).

KAATSU, which is an exercise combined with blood flow restriction (BFR), is one of method of trainings that uses a specially designed belt tightened near the joints of the upper arm or leg, applying pressure to the muscle and temporally restricting blood flow. Existing research has revealed that low-intensity KAATSU training could induce muscular hypertrophy and strength gain (Takarada *et al*., 2002). Abe *et al*. (2006) reported that the combination of slow walking and muscle BFR induces increases in muscle size and strength despite the minimal level of exercise intensity. Therefore, slow walking with BFR may be a potentially useful method to promote muscle hypertrophy, especially for the elderly. During slow walking with BFR, arterial flow is reduced and venous blood is pooled in the leg vein (Takano *et al*., 2005; Iida *et al*., 2007). Consequently, these changes might produce hydrostatic forces in the leg vein.

We hypothesized that this change affects leg venous compliance; therefore, in the present study, we investigated the effect of 6 weeks of walking with BFR on leg venous compliance in older women using non-invasive methods of determining limb venous compliance.

Methods

Subjects

Sixteen elderly women aged 59–78 years participated in this study. Subjects were partially randomized into either a slow walking with BFR group ($n = 9$) or a non-exercising control group ($n = 7$). The subjects were recruited by word of mouth. Volunteers were free of orthopaedic disorders. None of the subjects had participated in strength- or resistance-type training for at least 2 years prior to the start of the study. All subjects were informed of the methods, procedures and risks and signed an informed consent document before participation. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee for Human Experiments of the University of Tokyo, Japan.

Training protocol

The training was conducted once a day, 5 days per week for 6 weeks. The subjects walked on a motor-driven treadmill at 67 m min^{-1} for 20 min. The walking speed and duration remained constant throughout the training period. Subjects in the slow walking with BFR group wore pressure belts (Kaatsu-Master, Sato Sports Plaza, Tokyo) on both legs during the training. A non-exercising control group was advised to perform slow walking daily for 20 min 5 days per week during the study. During the study, all subjects were required not to perform any other strength- or resistance-type training or long running for more than 20 min.

Blood flow restriction (BFR)

Femoral blood flow was impaired using the KAATSU technique, which restricts venous blood flow causing pooling of blood in capacitance vessels distal to the cuff and partial occlusion of arterial blood flow (Takano *et al*., 2005; Iida *et al*., 2007; Nakajima *et al*., 2008). Prior to slow walking with BFR, the subjects were seated on chairs and the belt air pressure was repeatedly set (30 s) and then released (10 s) from an initial pressure of 100 mmHg to a final training pressure of 140 mmHg (Abe *et al*., 2006). The training pressure was increased by 10 mmHg each day until a final belt pressure of 200 mmHg was reached, although two subjects trained at 180 mmHg for the duration of the study. A restriction pressure of 140–200 mmHg was selected for the restriction stimulus based on a review of the data in young men (Abe *et al*., 2006). Blood flow to the leg muscles was restricted for a total time of about 23 min (20 min of walking and 3 min of preparation) during each training session for each subject, and the belt pressure was released immediately upon completion of the session.

Venous occlusion plethysmography

Venous occlusion plethysmography with multiple proximal occlusion pressure was used to obtain venous compliance measurements before and immediately after the study. A strain gauge (EC6 plethysmograph, Hokanson, Bellevue, WA, USA) was stretched around the largest girth of the right calf and forearm. Thigh and upper arm pressure cuffs were connected to a rapid cuff inflator (E20 rapid cuff inflator, Hokanson, Bellevue, WA, USA) to ensure rapid and accurate filling and deflating of the cuff. External pressure was applied on the thigh and upper arm through an occlusion cuff, which was attached to an electronically controlled air pump. Pressure levels of 20, 40, 60 and 80 mmHg were delivered consecutively after having reached a quasi-steady state at the previous level. We calculated the following parameters from the plethysmographic recordings (Bleeker *et al*., 2004). To be concise, venous volume variation (VVV) (in ml 100 ml^{-1}) was defined as the maximal relative volume increase in the limb at a certain cuff pressure; VVV at different occlusion pressures represents the pressure–volume curve. Venous compliance (ml 100 ml^{-1} $mmHg^{-1}$), the ratio of a change in volume (ΔV) to a concomitant change in the transmural distending pressure $(\Delta P) : V_c = \Delta V/\Delta P$ (Rothe, 1983, 1993), was derived from the slope of the pressure–volume curve. Maximal venous outflow (MVO) (in ml 100 ml^{-1} min^{-1}) was calculated as the slope of the tangent at the curve from 0·5 to 2·0 s after cuff release.

Statistical analyses

All values are presented as means ± SD. We used an unpaired Student's t-test to assess baseline differences between slow walking with BFR group and control group. We used a paired Student's *t*-test to examine the effect of the 6-week intervention in both groups. Differences were considered significant if $P<0{\cdot}05$.

Results

Table 1 summarizes the anthropometric characteristics and resting cardiovascular variables of all participants in the study. Three subjects in each group had hypertension, and no subjects

Table 1 Anthropometrical characteristics and resting cardiovascular variables.

	Control group	Blood flow restriction walk group
Age (year)	68·7 ± 2·8	67·4 ± 1·6
Height (cm)	150·1 ± 1·8	149·9 ± 1·2
Mass (kg)	52·7 ± 3·3	51·9 ± 2·3
BMI (kg m^{-2})	23·9 ± 1·0	23·1 ± 0·9
HR (bpm)	73·0 ± 3·6	76·8 ± 3·3
Systolic blood pressure (mmHg)	129·7 ± 8·2	148·2 ± 7·1
Diastolic blood pressure (mmHg)	71·7 ± 2·6	84·6 ± 3·8**
Leg compliance (ml 100 ml^{-1} $mmHg^{-1}$)	0·0686 ± 0·0160	0·0518 ± 0·0084*

**$P<0·01$, *$P<0·05$.

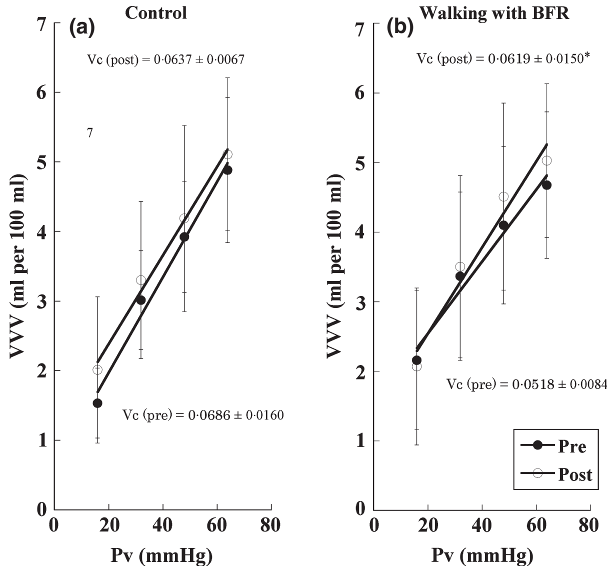

Figure 1 Pressure–volume curves for the leg (●: pre 6-week training and ○: post 6-week training). Venous volume variation (VVV) values are means ± SD. (a) Control group; (b) slow walking with BFR group. *$P<0.05$.

had heart failure or venous disease, such as varicose vein of lower extremity. Although pre intervention data of diastolic pressure differed significantly between the BFR walk group and control group, there were no significant differences between the two groups for age, standing height, body mass and body mass index. None performed regular moderate or vigorous physical activity before the study.

Venous compliance

Preintervention compliance of the control group was higher than that of the slow walking with BFR group (Table 1). After 6 weeks of training, leg compliance in slow walking with BFR group increased significantly (Fig. 1, pre: 0·0518 ± 0·0084 ml 100 ml^{-1} $mmHg^{-1}$, post: 0·0619 ± 0·0150 ml 100 ml^{-1} $mmHg^{-1}$, $P<0·05$) with significant change of leg girth (pre: 33·5 ± 0·8 cm, post: 33·9 ± 0·8 cm, $P<0·05$). Meanwhile, no significant differences were observed in the leg compliance of the control group (Fig. 1) and in the arm compliance of the BFR group (n = 6, Fig. 2).

Maximal venous outflow

Figure 3 depicts the MVO at each cuff pressure. Maximal venous outflow at 80 mmHg increased significantly after 6-week training in the slow walking with BFR group (pre: 55·3 ± 15·6 ml 100 ml^{-1} min^{-1}, post: 67·1 ± 18·9 ml 100 ml^{-1}·min^{-1}, $P<0·01$), but no significant difference was observed in the control group.

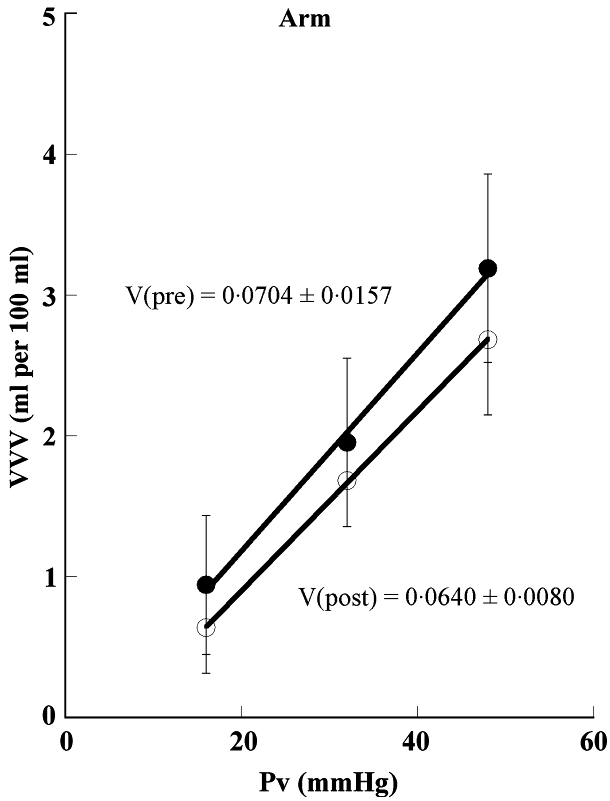

Figure 2 Pressure–volume curves for the arm obtained before and after slow walking with BFR for 6 weeks (●: pre 6-week training and ○: post 6-week training). Venous volume variation (VVV) values are means ± SD for six subjects. There was no significant change in arm venous compliance in contrast to the change of leg venous compliance.

Discussion

The present study provides new findings that 6 weeks of slow walking with BFR in elderly women induce significantly increased limb venous compliance and increased MVO. It is likely that the decline in venous compliance through ageing is reversible and that endurance exercise with xrestriction of leg blood flow improves the limb venous compliance.

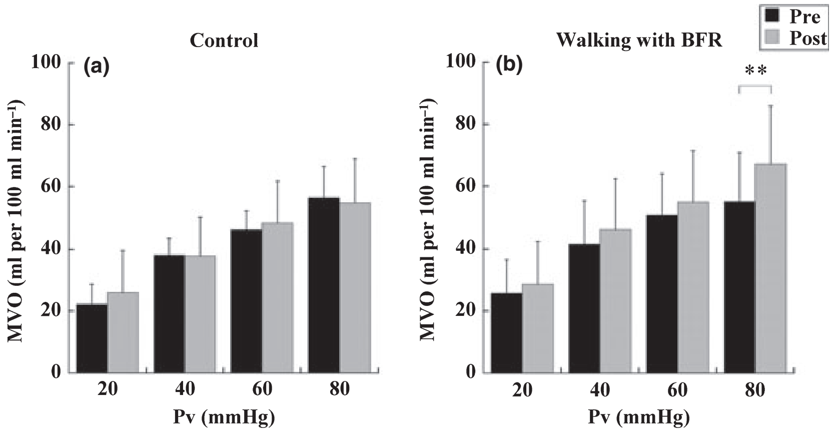

Figure 3 Effects of walking for 6 weeks on maximum venous flow in the leg of control group (a) and slow walking with BFR group (b). Maximal venous outflow (MVO) values are means ± SD. There was a significant change in the maximum venous flow at 80 mmHg in the slow walking with BFR group. **P<0.01.

Ageing induces the decline in limb venous compliance (Olsen & Länne, 1998), and this decline prevents the elderly from responding to acute deterioration of cardiovascular homeostasis. Furthermore, reduced venous compliance may be one of the risk factors of varicose veins and deep vein thrombosis. Therefore, we need some way to counter the decline in venous compliance.

Until now, several authors have demonstrated that venous compliance is improved by endurance exercise. Hernandez & Franke (2005) studied the influence of a 6-month endurance-training programme on calf venous compliance in older men and women and revealed that it tended to be 20–30% greater in the exercise group after 6 months of training compared with control group. Monahan *et al.* (2001) sought to determine the reciprocal influences of ageing and habitual endurance exercise on calf venous compliance in humans, and they demonstrated that venous compliance declined with age and that calf venous compliance was approximately 70–120% greater in endurance-trained men compared with age-matched sedentary men and approximately 30% greater in older endurance-trained men compared with young sedentary. These data suggest that endurance training is useful for improving age-related decline in venous compliance.

In the present study, we suggested that slow walking with BFR (Abe *et al.*, 2006) can induce significant improvement in limb venous compliance in elderly women over shorter periods compared with simple endurance exercise.

Although the mechanism of this prominent improvement is unclear, we can infer that slow walking with BFR has additional effects over simple endurance exercise. Because subjects wear a belt around their legs during walking with BFR, slow walking with BFR not only increases physical activity more than endurance exercise does but also changes hydrostatic force in the leg through BFR, and these changes may affect venous vascular function synergistically. As previously reported, venous blood outflow and arterial inflow are restricted, and blood pooling in the lower extremities is produced during walking with BFR (Takano *et al.*, 2005; Iida *et al.*, 2007). During slow walking with BFR, venous pooling might induce the alteration in hydrostatic force in the lower extremities, and altered hydrostatic force affects cardiovascular reflex responses and, consequently, venous properties more quickly and more effectively than simple endurance exercise.

According to Bleeker *et al.* (2004), after 18 days of head-down-tilt bed rest, leg venous compliance is reduced and leg venous outflow resistance is increased. In the report, they concluded that altered gravitational gradients induce alteration in hydrostatic forces and cardiovascular reflex responses. In their study, the deconditioning induced by 18 days of bed rest led to no significant differences in arm venous vascular properties. In the present study, arm venous compliance was not affected by slow walking with BFR. This differential response between legs and arms may support our inference that walking with BFR may affect hydrostatic gradients only in the leg and that this change plays an important role in improving leg venous function.

Muscle compartment, which can compress the veins and resist the expansion of the veins, is thought to be one of the structural factors to influence the venous compliance. Convertino *et al.* (1988, 1989) found that reduced muscle compartment leads the increased leg compliance observed after exposure to simulated microgravity. In the present study, despite the fact that the girth increased significantly after 6 weeks walking with BFR, the venous compliance increased significantly. This suggests that the increase in limb venous compliance was not caused by the increase in muscle mass.

Haemodynamic factors may affect the venous compliance. Although blood pressure was not checked during exercise, some studies revealed that elevation of blood pressure during walking with BFR is lower compared with high-intensity resistance training (Sakamaki *et al.*, 2008), and there was no significant change in blood pressure after 6 weeks in the present study (data not shown). Furthermore, other factors than muscle size and blood pressure may influence the result, but no remarkable changes in anthropometrical characteristics were observed, and we could not find the special characteristics of the responder or non-responder.

However, as a result of the small sample size in this study and the significant difference of preintervention data in leg venous compliance between groups, statements must be made carefully and further investigation is required. Furthermore, as we did not check the state of venous valves during compression of the legs in the present study, more detailed investigation in the state of valves, hydrostatic forces and cardiovascular reflex response is required to make the mechanism clear.

In conclusion, 6 weeks of slow walking with BFR in elderly subjects significantly induced increased limb venous compliance. Also, slow walking with BFR may be a novel method for improving limb venous compliance in elderly women.

Conflicts of interest

Dr Sato Y is the Managing Director of Best Life Co., Ltd, and President of Sato Sports Plaza Co., Ltd. (and a stockholder of both companies) and is the inventor of the KAATSU Training method. He also received U.S. Patent No. 6,149,618 and corresponding patents outside the United States. (all assigned to Best Life Co., Ltd.) and is the inventor of other applications and patents (assigned to Sato Sports Plaza Co., Ltd.) related to KAATSU Training.

References

Abe T, Kearns CF, Sato Y. Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, Kaatsu-walk training. *J Appl Physiol* (2006); **100**: 1460–1466.

Bleeker MW, De Groot PC, Pawelczyk JA, Hopman MT, Levine BD. Effects of 18 days of bed rest on leg and arm venous properties. *J Appl Physiol* (2004); **96**: 840–847.

Convertino VA, Doerr DF, Flores JF, Hoffler GW, Buchanan P. Leg size and muscle functions associated with leg compliance. *J Appl Physiol* (1988); **64**: 1017–1021.

Convertino VA, Doerr DF, Stein SL. Changes in size and compliance of the calf after 30 days of simulated microgravity. *J Appl Physiol* (1989); **66**: 1509–1512.

Fu Q, Iwase S, Kamiya A, Michikami D, Niimi Y, Mano T. Regulation of the venous capacitance during microgravity. *J Gravit Physiol* (2000); **7**: 19–22.

Hernandez JP, Franke WD. Effects of a 6-mo endurance-training program on venous compliance and maximal lower body negative pressure in older men and women. *J Appl Physiol* (2005); **99**: 1070–1077.

Iida H, Kurano M, Takano H, Kubota N, Morita T, Meguro K, Sato Y, Abe T, Yamazaki Y, Uno K, Takenaka K, Hirose K, Nakajima T. Hemodynamic and neurohumoral responses to the restriction of femoral blood flow by KAATSU in healthy subjects. *Eur J Appl Physiol* (2007); **100**: 275–285.

Louisy F, Jouanin JC, Guezennec CY. Filling and emptying characteristics of lower limb venous network in athletes: study by postural plethysmography. *Int J Sports Med* (1997); **18**: 26–29.

Monahan KD, Dinenno FA, Seals DR, Halliwill JR. Smaller age-associated reductions in leg venous compliance in endurance exercise-trained men. *Am J Physiol Heart Circ Physiol* (2001); **281**: H1267–H1273.

Nakajima T, Iida H, Kurano M, Takano H, Morita T, Meguro K, Sato Y, Yamazaki Y, Kawashima S, Ohshima H, Tachibana S, Ishii N, Abe T. Hemodynamic responses to simulated weightlessness of 24-h head-down bed rest and KAATSU blood flow restriction. *Eur J Appl Physiol* (2008); **104**: 727–737.

Olsen H, Länne T. Reduced venous compliance in lower limbs of aging humans and its importance for capacitance function. *Am J Physiol* (1998); **275**: H878–H886.

Olsen H, Vernersson E, Länne T. Cardiovascular response to acute hypovolemia in relation to age. Implications for orthostasis and hemorrhage. *Am J Physiol Heart Circ Physiol* (2000); **278**: H222–H232.

Pareira DM, Handler FP, Blumenthal HT. Aging processes in the arterial and venous systems of the lower extremities. *Circulation* (1953); **8**: 36–43.

Rothe CF. Reflex control of veins and vascular capacitance. *Physiol Rev* (1983); **63**: 1281–1342.

Rothe CF. Mean circulatory filling pressure: its meaning and measurement. *J Appl Physiol* (1993); **74**: 499–509.

Sakamaki M, Fujita S, Sato Y, Bemben MG, Abe T. Blood pressure response to slow walking combined with KAATSU in elderly. *Int J KAATSU Training Res* (2008); **4**: 17–20.

Takano H, Morita T, Iida H, Asada K, Kato M, Uno K, Hirose K, Matsumoto A, Takenaka K, Hirata Y, Eto F, Nagai R, Sato Y, Nakajima T. Hemodynamic and hormonal responses to a short-term low-intensity resistance exercise with the reduction of muscle blood flow. *Eur J Appl Physiol* (2005); **95**: 65–73.

Takarada Y, Sato Y, Ishii N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol* (2002); **86**: 308–314.

Tsutsui Y, Sagawa S, Yamauchi K, Endo Y, Yamazaki F, Shiraki K. Cardiovascular responses to lower body negative pressure in the elderly: role of reduced leg compliance. *Gerontology* (2002); **48**: 133–139.

Wecht JM, de Meersman RE, Weir JP, Bauman WA, Grimm DR. Effects of autonomic disruption and inactivity on venous vascular function. *Am J Physiol Heart Circ Physiol* (2000); **278**: H515–H520.