Involvement of RhoA/Rho Kinase Pathway in Myogenic Tone in the Rabbit Facial Vein

Caroline Dubroca, Dong You, Bernard I. Lévy, Laurent Loufrani, Daniel Henrion

Abstract—Myogenic tone (MT), a fundamental stretch-sensitive vasoconstrictor property of resistance arteries and veins, is a key determinant of local blood flow regulation. We evaluated the pathways involved in MT development. The role of the RhoA/Rho kinase, p38 MAP kinase, and HSP27 in MT was investigated in the rabbit facial vein (RFV), previously shown to possess MT at a pressure level equivalent to 20 mm Hg. Venous MT is poorly understood, although venous diseases affect a large proportion of the population. Stretched RFV are characterized by a temperature-sensitive MT, which is normal at 39°C but fails to develop at 33°C. This allows for the discrimination of the pathways involved in MT from the multiple pathways activated by stretch. Isolated RFV segments were mounted in organ baths and stretched. Temperature was then set at 33°C or 39°C. MT was associated to the translocation of RhoA to the plasma membrane and the Rho kinase inhibitor Y27632 decreased stretch-induced MT by 93.1±4.9%. MT was also associated to an increase in p38 (131.0±12.5% at 39°C versus 100% at 33°C) and HSP27 phosphorylation (196.1±13.3% versus 100%), and the p38 MAP kinase inhibitor SB203580 decreased MT by 36.5±8.1%. (39°C, compared with RFV stretched at 33°C). Finally, phosphorylation of p38 was blocked by Y27632 and HSP27 phosphorylation was inhibited by SB203580 and Y27632. Thus, MT and the associated p38 and HSP27 phosphorylation seem to depend on RhoA/Rho kinase activation in stretch RFV. (Hypertension. 2005;45:974-979.)

Key Words: signal transduction ■ kinase ■ heat shock proteins

The process of matching blood flow to metabolic demand through changes in perfusion pressure is determined to a large extent by myogenic tone (MT). Myogenic properties of vessels include 2 processes: basal MT and myogenic response. Basal MT is a constant vasoconstriction caused by the transmural pressure or stretch applied to the arterial wall. Myogenic response is characterized by a smooth muscle cells contraction in response to increase in pressure or stretch. 1 The myogenic response participates in the local regulation of blood flow and protects downstream capillary beds from large increases in hydrostatic pressure, such as that induced by postural changes, and an increase in the amplitude of MT can also occur in response to an increase in perfusion pressure is determined to a large extent by myogenic tone (MT). Myogenic properties of vessels include 2 processes: basal MT and myogenic response. Basal MT is a constant vasoconstriction caused by the transmural pressure or stretch applied to the arterial wall. Myogenic response is characterized by a smooth muscle cells contraction in response to increase in pressure or stretch. 1 The myogenic response participates in the local regulation of blood flow and protects downstream capillary beds from large increases in hydrostatic pressure, such as that induced by postural changes, and an increase in the amplitude of MT is associated with hypertension 2 and diabetes mellitus. 3 Signaling mechanisms that contribute to MT require calcium entry, protein kinase C, 4 and phospholipase C activation, 5 as well as calcium-sensitization of the contractile apparatus. 1,6–9 There is also growing evidence that actin polymerization and the dynamic remodeling of the actin cytoskeleton play an important role in MT. 10 In addition, Ca 2+ and myosin light chain (MLC) phosphorylation are key regulators of the dynamic reorganization of actin filaments. In recent years, evidence has accumulated that the ras-related small GTP-binding protein Rho is another important signaling element that mediates various actin-dependent cytoskeletal functions, including smooth muscle contraction. However, its roles in different signal transduction cascades may vary depending on the cell type. 11 The role of mitogen-activated protein (MAP) kinases, which may also affect smooth muscle contractility, 12 in pressure myogenic contraction have not been fully explored. 8 Using the rabbit facial vein (RFV), we have previously shown that ERK1/2 activation, although stimulated by stretch, is not linked to MT. 13 In another study, in resistance arteries, we found that activation of p38 MAP kinase contributes to vascular smooth muscle contraction induced by agonists such as thromboxane A 2. 14 Furthermore, it has been shown that endothelin-1 activates p38 MAP kinase pathways and heat shock protein (HSP) 27, and that p38 could regulate phosphorylation of HSP27. 15 A specific role has been found for HSP27 in the regulation of actin cytoskeletal dynamics, based on the ability of HSP27 to modulate phosphorylation-dependent actin polymerization. 16–18 Thus, we hypothesized that RhoA/Rho kinase and p38–HSP27 might play a role in myogenic contraction.

Nevertheless, a main difficulty in studying MT is that stretch per se activates multiple pathways not necessarily involved in MT. Stretch and MT cannot easily be dissociated; classically, arteries submitted to pressure (thus developing MT because of stretch) are compared with unstretched arteries (absence of pressure). 8 To bypass this difficulty, we used the RFV that develops MT to a degree similar to that...
observed in resistance arteries but that is temperature-sensitive. At equal stretch, MT that is observed in the RFV at 39°C is absent at 33°C. Using the RFV is also opening an important perspective in the understanding of vein pathophysiology. The control of venous tone is poorly understood and sparsely studied. Venous tone changes with aging, hypertension, or diabetes. MT occurs in the RFV with a stretch level (5 mN in a 3- to 4-mm-long segment) corresponding to a blood pressure ~20 mm Hg, which is within the normal range in veins. Thus, MT may play a role in venous tone regulation even though the system is operating at low pressures.

Therefore, we used the RFV model allowing the comparison of stretched vessels with (39°C) or without (33°C) MT to test the hypothesis that p38, HSP27, or RhoA activation could be involved in or affected by the development of MT in RFV.

**Materials and Methods**

**RFV**

Buccal segments of the facial vein were isolated as previously described from male New Zealand White rabbits (2.5 to 2.7 kg). The procedure used was in accordance with the European Community standards on the care and use of laboratory animals (authorization 00577); 3-mm-long ring segments of RFV were mounted between parallel stainless steel wires in 5-mL organ baths. One wire was attached to a fixed support, whereas the other was connected to a moveable holder supporting a tension transducer, so that isometric force could be recorded and data were collected (Biopac MP 100). Vein segments were maintained at 33°C in a physiological salt solution (PSS) of the following composition (mmol/L): 135 NaCl, 15 NaHCO3, 4.6 KCl, 1.5 CaCl2, 1.2 MgSO4, 11 glucose, 10 N-2-hydroxyethylpiperazine-N-2-ethylsulfonic acid (pH 7.4), PO2 160 mm Hg, and Pco2 37 mm Hg.

Each segment was submitted to one of the following protocols: (1) RFV segments were subjected to a 5.0-mN force (stretch), which is optimal for the development of MT7,13 and allow to stabilize for 30 minutes, in the absence (33°C) of MT; (2) RFV segments, after stabilization at 33°C, were maintained at 33°C or warmed to 39°C and exposed or not (time control group) to (10 μmol/L to 10 μmol/L) the Rho kinase inhibitor Y27632 or the p38 MAP kinase inhibitor SB203580; and (3) RFV were just bathed in PSS, without stretch, at 33°C or 39°C.

**P38 MAP Kinase and HSP27 Activation**

Phosphorylation p38 (phospho-p38) and HSP27 (phospho-HSP27) were quantified in RFV segments using Western blot analysis. Tissue extraction was performed as previously described13,12 frozen vessel segments were pulverized in liquid nitrogen (LN2). The powders were resuspended in ice-cold homogenization buffer of the following composition: 300 mmol/L sucrose, 1 mmol/L Na3, 20 mmol/L N-2-hydroxy-ethylpiperazine-N-2-ethylsulfonic acid pH 7.4, and protease inhibitors (Boehringer Mannheim) and centrifuged at 31 000g for 30 minutes (ultracentrifuge; Beckman). The supernatant was collected as the cytosolic fraction. Pellets were resuspended, and the membrane proteins were extracted by incubation in homogenization buffer (0.1 mol/L NaCl, 30 mmol/L imidazole, 8% sucrose, 1 mmol/L Na3, pH 6.8, and protease inhibitors [Boehringer Mannheim]). The extract was centrifuged at 10 000g at 4°C. The supernatant was collected as the membrane fraction. Immunoreactive bands for Rho A in cytosolic and membrane fractions were processed as described for Western blots with anti-Rho A (Santa Cruz) as primary antibody.

**Drugs**

SB203580 and Y27632 were purchased from Calbiochem (La Jolla, Calif); all other reagents were purchased from Sigma (St Louis, Mo). SB203580 and Y27632 were dissolved in water.

**Statistical Analysis**

Results are expressed as mean±SEM. The significance of the different treatments was determined by ANOVA or 2-tailed Student paired t test. P<0.05 were considered to be significant.

**Results**

In RFV segments, MT develops at 39°C, whereas it is absent when the temperature is maintained at 33°C (Figure 1). As previously shown,2,5 after reducing temperature to 33°C, the addition of papaverine (10 μmol/L) does not further relax the vein (not shown).

In RFV at 39°C exposed to stretch, the Rho kinase inhibitor Y27632 induced a concentration-dependent reduction of MT (Figure 1, lower panel, and Figure 2). The p38 MAP kinase inhibitor SB203580 attenuated MT in a dose-dependent way but to a lesser extent than Y27632 (Figure 2): Y27632 (10 μmol/L) reduced MT to 6.9±5.0% of control (stretched

![Figure 1](http://hyper.ahajournals.org/)

Figure 1. Typical recordings showing wall tension in a rabbit facial vein segment mounted in a myograph. A, myogenic tone fully developed at 39°C and is absent when bath temperature is 33°C. B, the inhibitory effect of cumulative concentration (0.1 to 10 μmol/L) of the Rho kinase inhibitor Y27632.
RFV at 39°C) and SB230580 (10 µmol/L) to 63.5 ± 8.1% of control.

As suggested by the contraction experiment (Figure 3A), RhoA/Rho kinase could be involved in stretch-induced MT. This is confirmed by the blot (Figure 3B) showing that in absence of MT (33°C), RhoA is more concentrated in the cytosol fraction, whereas in the presence of MT (39°C) RhoA is translocated from the cytoplasm to the plasma membrane.

The phosphorylation of p38–MAP kinase was determined in RFV segments submitted to stretch in the absence (33°C) or in the presence (39°C) of MT, with or without Y27632 (10 µmol/L). The effect of temperature was also evaluated and basal p38 phosphorylation was considered to be 100% in unstretched RFV segments at 33°C. Figure 4A shows that p38 phosphorylation was not affected by temperature in unstretched veins. At 33°C, stretch induced a significant increase of p38 phosphorylation (141.0 ± 11.0%) compared with unstretched veins. This activation of p38 was not significantly affected by Y27632 (Figure 4A).

Then, we measured p38 activation in the presence of stretch at 33°C (without MT) and at 39°C (with MT). Basal p38 phosphorylation was considered to be 100% in vein segments stretched at 33°C. Stretch at 39°C was also associated with an increased in p38 phosphorylation (141.0 ± 11.0%) compared with unstretched veins. This activation of p38 was not significantly affected by Y27632 (Figure 4A).

In another series of experiments, HSP27 phosphorylation was determined in RFV segments submitted or not to stretch at 33°C or 39°C and in the presence or absence of Y27632 (10 µmol/L) or SB203480 (10 µmol/L). In unstretched RFV segments, the temperature had no significant effect on HSP27 phosphorylation (131.0 ± 12.5%) and Y27632 completely blocked p38 phosphorylation associated with MT (Figure 4B).

In another series of experiments, HSP27 phosphorylation was determined in RFV segments submitted or not to stretch at 33°C or 39°C and in the presence or absence of Y27632 (10 µmol/L) or SB203480 (10 µmol/L). In unstretched RFV segments, the temperature had no significant effect on HSP27 phosphorylation (131.0 ± 12.5%) and Y27632 completely blocked p38 phosphorylation associated with MT (Figure 4B).

Discussion

In this study, we found that Rho kinase inhibition suppressed MT in the rabbit facial vein. Furthermore, MT was associated to RhoA translocation from the cytosol to the plasma membrane. These results suggest that the RhoA/Rho kinase pathway plays a major role in MT. These results are consistent with a previous work showing that Y27632 caused a dose-dependent inhibition of basal tone in cannulated rat mesenteric resistance arteries, with almost total inhibition at 3 µmol/L. They differ from another study showing that Y27632 only partly attenuated MT in rat tail small arteries. This discrepancy may reflect a difference in the degree of participation of Rho kinase in MT in different vessels and/or a difference in its interaction with other kinases. It has been
shown that a Ca\(^{2+}\) sensitization may contribute to MT,\(^{27}\) and recent evidence for the involvement of the small GTPase RhoA in Ca\(^{2+}\) sensitization in smooth muscle contraction has been reported by several laboratories.\(^{28-30}\) Rho kinase, the RhoA effector, can directly modulate smooth muscle contraction through MLC phosphorylation, independently of the Ca\(^{2+}\)-calmodulin–dependent myosin light chain kinase pathway.\(^{31}\) Rho kinase is able to regulate MLC phosphorylation by the direct phosphorylation of MLC and by the inactivation of myosin phosphatase through phosphorylation of the myosin binding subunit.\(^{32}\) Therefore, Rho kinase and myosin phosphatase coordinate to regulate the phosphorylation state of MLC and, as a result, induce smooth muscle contraction.

Our results also indicate that SB203580, the specific p38 MAP kinase inhibitor, attenuated MT in a concentration-dependent manner. In addition, p38 phosphorylation was significantly higher in RFV segments stretched at 39°C, thus developing MT, than in vein segments stretched at 33°C. Furthermore, our findings show that Y27632 inhibited contraction-induced p38 phosphorylation, suggesting that RhoA/Rho kinase activation was upstream of p38 and induced its activation. Our findings are consistent with a previous study suggesting that p38 MAP kinase activation could be involved in the mechanotransduction of wall tension in gracilis muscle arterioles.\(^{6}\) Studies in large vessels and isolated smooth muscle cells suggested that MAP kinase activation contributes to vascular smooth muscle contraction induced by endothelin-1 \(^{33-35}\) and angiotensin II.\(^{36}\) In the rat thoracic aorta, p38 may partly regulate endothelin-1–induced contraction through a MLC phosphorylation-independent pathway.\(^{33}\) Recently, the p38 MAPK/HSP27 pathway has been suggested to be involved in the generation of maximal force development. Some of the important downstream events coupled with p38 MAP kinase activation include phosphorylation of MAPK-activated protein kinases 2 and 3, which in turn phosphorylate HSP27.\(^{37,38}\) Phosphorylation of HSP27 is another MAP kinase-mediated mechanism that has been proposed to modulate the maintenance of the contractile response of vascular smooth muscle.\(^{39,40}\) In this study, we found that HSP27 was activated in conditions of MT development and that RhoA and p38 were needed for this activation. Nevertheless, that HSP27 is phosphorylated does not necessarily imply that it is directly involved in MT. Several reports suggest that HSP27 might modulate actin filament dynamics and be involved in contraction of smooth muscle cells. HSP27, in its nonphosphorylated state, behaves as a phosphorylation-regulated F-actin capping protein capable of inhibiting actin polymerization.\(^{41,46}\) Phosphorylation of HSP27, via activation of p38, might markedly modify the equilibrium in favor of polymerized actin, thereby contributing to the maintenance of the microfilament network.\(^{42}\) Studies in cells transiently transfected with dominant-negative RhoA suggest that RhoA might exert its effects on cytoskeleton reorganization through HSP27 and that cytoskeletal proteins might interact to induce sustained smooth muscle contraction.\(^{11}\) It is still unclear whether RhoA interacts with HSP27, but our work suggests that RhoA via the activation of Rho kinase stimulated p38, leading to HSP27 phosphorylation.

It should be noted that we used a vein that may not be representative of resistance arteries, most usually used in the study of MT. Nevertheless, the RFV shares several common features with arteries, including histological features and a strong capacity to contract.\(^{43}\) Nevertheless, each specific blood vessel (and this applies to arteries) has specific features and extrapolation must always be considered carefully. The RFV has this unique feature allowing comparison of stretched vessels with or without MT. This is a key issue of the present study because stretch per se activates many pathways not necessarily involved in MT, as we have previously shown with ERK1/2.\(^{13}\) In addition, because the RFV is a vein, our study opens an important perspective in the study of venous tone. It is estimated that 75% of the total blood volume in the resting state is contained within venules and veins. Therefore, constriction or dilation of veins would have a greater effect on changing blood volume distribution than any other part of the vasculature.\(^{44,45}\) The factors controlling venoconstriction are complex and include neural and humoral mechanisms. The increased sympathetic nerve activity results in augmented venoconstriction, which predominates in the development of spontaneous hypertension.\(^{46}\)
In conclusion, this study brings new insights in the understanding of venous myogenic contraction showing a complete involvement of RhoA/Rho kinase and a partial involvement of p38 MAP kinase, and it might provide a novel mechanism insight on increased venoconstriction in hypertension. In conditions of MT development, pressure might activate RhoA, which plays a major role in the development of MT through sensitization of the contractile apparatus to calcium.

In parallel, RhoA/Rho kinase would also activate p38 MAP kinase, which would then activate HSP27 phosphorylation, possibly inducing cytoskeletal rearrangement by facilitating thin-filament regulation of smooth muscle contraction.

Acknowledgments
This work was supported in part by a grant from the French Foundation for Medical Research (Fondation pour la Recherche Médicale [FRM], Paris, France). L.L. and C.D. were fellows of the FRM (Paris, France).

References


Involvement of RhoA/Rho Kinase Pathway in Myogenic Tone in the Rabbit Facial Vein
Caroline Dubroca, Dong You, Bernard I. Lévy, Laurent Loufrani and Daniel Henrion

Hypertension. 2005;45:974-979; originally published online April 18, 2005;
doi: 10.1161/01.HYP.0000164582.63421.2d
Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2005 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the
World Wide Web at:
http://hyper.ahajournals.org/content/45/5/974

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published
in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial
Office. Once the online version of the published article for which permission is being requested is located,
click Request Permissions in the middle column of the Web page under Services. Further information about
this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/