Sphingosine-1-Phosphate Receptor-2 Regulates Expression of Smooth Muscle Alpha-Actin After Arterial Injury

Allison D. Grabski, Takuya Shimizu, Jessie Deou, William M. Mahoney Jr, Michael A. Reidy, Guenter Daum

Objective—This study tests the hypothesis that S1P2R regulates expression of SMC differentiation genes after arterial injury.

Methods and Results—Carotid ligation injury was performed in wild-type and S1P2R-null mice. At various time points after injury, expression of multiple SMC differentiation genes, myocardin, and S1P receptors (S1P1R, S1P2R, and S1P3R) was measured by quantitative PCR. These experiments demonstrate that at day 7 after injury, S1P2R specifically regulates expression of smooth muscle α-actin (SMA) and that this is not mediated by changes in expression of myocardin or any of the S1PRs. In vitro studies using carotid SMCs prepared from wild-type and S1P2R-null mice show that S1P stimulates expression of all SMC-differentiation genes tested, but S1P2R significantly regulates expression of SMA and SM22α only. Chromatin immunoprecipitation assays suggest that S1P-induced recruitment of serum response factor to the SMA promoter and enhancer largely depends on S1P2R. S1P-stimulated SMA expression requires S1P2R-dependent activation of RhoA and mobilization of calcium from intracellular stores. Chelation of calcium does not affect the activation of RhoA by S1P, whereas blockade of Rho by C3 exotoxin partially inhibits the mobilization of calcium by S1P.

Conclusions—The results of this study support the hypothesis that S1P2R regulates expression of SMA after injury. We further conclude that transcriptional regulation of SMA by S1P in vitro requires S1P2R-dependent activation of RhoA and mobilization of calcium from intracellular calcium stores. (Arterioscler Thromb Vasc Biol. 2009;29:1644-1650.)

Key Words: sphingosine-1-phosphate ■ S1P2R ■ smooth muscle actin ■ Rho ■ calcium

Restenosis is a major complication of surgical procedures performed to restore arterial blood flow. Despite all efforts, pharmacological inhibition of restenosis has not yet been achieved. In normal arteries, smooth muscle cells (SMCs) are quiescent and regulate vascular tone. After arterial injury, medial SMCs proliferate and lose expression of genes encoding the contractile apparatus, a process referred to as phenotypic modulation.1,2 It is generally believed that decreased expression of these “differentiation genes” is instrumental for the increased proliferative potential of SMCs after injury, although the exact molecular mechanisms remain to be defined. In this study, we test the hypothesis that one of the pathways regulating phenotypic modulation after arterial injury involves the sphingosine-1-phosphate receptor-2 (S1P2R).

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The bioactive sphingolipid S1P is best known for its regulation of lymphocyte egress from lymphatic organs3,4 and its requirement for vessel formation in development.5 Both processes are mediated by S1P1R, one of the 5 G protein–coupled receptors that bind S1P. SMCs express 3 S1P receptors (S1P1R, S1P2R and S1P3R). Concomitant pharmacological blockade of S1P1R and S1P3R inhibits neointimal growth in balloon-injured rat carotid arteries,6 suggesting a lesion-promoting role for S1P. Consistent with this conclusion, increased S1P concentrations in human serum were found to be highly predictive for the onset and progression of coronary artery disease.7 In contrast, we have recently suggested an inhibitory role for S1P in arterial lesion growth based on our observation that S1P2R-null mice but not their wild-type littermates develop large intimal lesions after carotid injury.8 In this study, medial proliferation was increased in S1P2R-null arteries compared to wild-type arteries, indicating that S1P2R prevents SMC proliferation.8 In addition to SMC migration and proliferation, S1P has been shown to induce expression of SMC differentiation genes such as smooth muscle α-actin (SMA), and this effect has been ascribed to activation of Rho.9,10 Activation of most promoters of SMC differentiation genes require binding of the transcription factor serum response factor (SRF) in combination with myocardin or a myocardin-related-transcription factor (MRTF) as a cofactor.1,11,12 Upon activation of Rho and stimulation of actin polymerization, cytosolic MRTF is released from G-actin and translocates into the nucleus. The physiological relevance of this process has been shown in proepicardial cells in which blockade of Rho kinase prevents their differentiation to coronary SMCs.13 Recently, a role for voltage-gated calcium channels (VGCCs) in the expression of
SMC differentiation genes in rat SMCs has been suggested. In KCl-treated cells, blockade of VGCCs by nifedipine attenuated SMA expression.\textsuperscript{14} Moreover, S1P-induced membrane translocation of RhoA was decreased by pretreatment of SMCs with nifedipine.\textsuperscript{6}

The present study tests the hypothesis that S1P2R regulates expression of SMC differentiation genes after arterial injury and investigates the potential signaling pathways involved.

**Methods**

**Materials**

S1P was purchased from Cayman and thrombin from American Diagnostica Inc. Antibodies were from Abcam (SM22α, β-actin), Cell Signaling (β-tubulin), Santa Cruz (SRF, Pol II, rabbit IgG-1α). Sigma (SM22, mouse IgG-1α). The ECL-kit, horseradish peroxidase (HRP)-coupled antimouse antibody, and HRP-coupled protein A, and protein A sepharose beads were from GE Healthcare. C3 exotoxin was from Cytoskeleton, BAPTA-AM and thapsigargin from Calbiochem, and nifedipine from Sigma. Custom primers and probes were purchased from Invitrogen or Integrated DNA Technologies. All primer and probe sequences are shown in supplemental Table I (available online at http://atvb.ahajournals.org).

**Animals, Surgical Procedures, and Isolation of Carotid SMCs**

S1P2R-null mice and wild-type mice were kindly provided by Dr Richard L. Proia (National Institutes of Health, Bethesda, Md).\textsuperscript{15} Heterozygous mice were bred to generate S1P2R-null and wild-type littermates. Genotypes were verified by polymerase chain reaction analysis using specific primers.\textsuperscript{15} The left common carotid artery of male mice (8 to 10 weeks old) was dissected and ligated near the carotid bifurcation as previously described.\textsuperscript{16} At the indicated time points, carotid arteries were excised and immediately frozen in liquid nitrogen or transferred to RNALater (Ambion). Carotid SMCs were isolated as previously described\textsuperscript{17} and maintained in DMEM supplemented with antibiotics (200 U/mL penicillin, 0.2 mg/mL streptomycin, all from Gibco) and 10% fetal bovine serum (Atlantic Biologics).

**Analysis of Gene Expression by Real-Time PCR and Western Blot Analysis**

Standard protocols were used to analyze gene expression by real-time PCR and Western blot analysis using preparations of total RNA and protein, respectively. Please see the supplemental materials for detailed methods, including primer sequences (supplemental Table I).

**Chromatin Immunoprecipitation Assay**

Chromatin Immunoprecipitation (ChIP) assays were performed with minor adjustments as recently described.\textsuperscript{18} Please see the supplemental materials for detailed methods including primer sequences (supplemental Table II).

**RhoA Assay**

Rho activity was measured using a commercially available kit as to the manufacturer’s instructions (Cytoskeleton).

**Calcium Measurement**

Serum-starved SMCs were loaded with 3 μmol/L Fluo4 calcium indicator dye (Molecular Probes, Invitrogen) for 30 minutes and rinsed with Tyrode solution. SMCs were stimulated with S1P (1 μmol/L) or KCl (60 mmol/L), and changes in fluorescence were imaged once every second for 150 seconds using confocal microscopy (LSM-510, Carl Zeiss; excitation: 488 nm; emission: 505 to 570 nm). The pixel intensities were quantified using NIH ImageJ software.

**Statistics**

As indicated in figure legends, data are presented as mean±SD or SEM. Significance of differences between 2 groups was calculated using Student t test, and Bonferroni adjustments were used for multiple variant analyses. Multiple isolations of SMCs were used in all in vitro experiments.

**Results**

**S1P2R Regulates Expression of SMA After Arterial Injury**

We recently reported that S1P2R-deficient arteries respond to injury with the formation of a large neointima, whereas wild-type arteries do not.\textsuperscript{9} In agreement with this observation, we observed increased medial proliferation in injured S1P2R-null arteries compared to wild-type arteries.\textsuperscript{8} To test the possibility that S1P2R regulates expression of SMC differentiation genes thereby controlling injury-induced phenotypic modulation, we measured mRNA of SMA, SM22α, calponin-1 (CNN1), and smooth muscle-myosin heavy chain (SM-MHC) in carotid arteries of S1P2R-null and wild-type mice at day 0, 2, 4, and 7 after injury. Expression of each gene tested decreased with injury (Figure 1A). At day 7, however, only SMA was significantly lower expressed in S1P2R-null arteries compared to wild-type arteries (Figure 1A). Neither myocardin, S1P1R, nor S1P3R were differentially expressed between wild-type and S1P2R-null arteries after injury (Figure 1A and 1B), and therefore none of these genes is likely to mediate S1P2R-dependent SMA expression after injury. To confirm RNA expression data, we measured SMA and SM22α protein as well. Whereas SMA is present at similar levels in uninjured wild-type and S1P2R-null arteries, its expression at day 7 and 14 after injury decreased significantly in S1P2R-null arteries only (by 30%, at day 7; supplemental Figure 1). Such differences were not observed for SM22α (supplemental Figure 1).

**S1P2R Regulates Expression of SMA in Response to S1P**

In vitro, S1P has previously been shown to stimulate SMA expression in SMCs, and a role for S1P2R and possibly S1P3R in this process has been suggested.\textsuperscript{9} Using wild-type and S1P2R-null SMCs in vitro, we found that expression of SMA, SM22α, CNN1, and SM-MHC, but not myocardin, is induced by S1P (Figure 2A). A significant difference between wild-type and S1P2R-null SMCs, however, was observed with SMA and SM22α only, both of which were more strongly induced in wild-type SMCs (Figure 2A). The same difference, although less pronounced, was observed for SMA and SM22α protein (Figure 2B). As SMA expression is regulated by SRF, we performed ChIP assays to investigate whether SRF enrichment at the promoter or the enhancer region in the first intron of the SMA gene are regulated by S1P2R. In wild-type SMCs, S1P increased enrichment of SRF at both sites by approximately 5-fold (Figure 3A). In S1P2R-null SMCs, enrichment of SRF before or after S1P stimulation was significantly less (Figure 3A). To demonstrate that S1P also stimulates transcription of the SMA gene, we determined binding of RNA polymerase II (Pol II) to the promoter and enhancer region. Binding of Pol II to either region...
was stimulated by S1P in both cell types but markedly decreased in S1P2R-null SMCs compared to wild-type SMCs (Figure 3B).

**SIP-Induced SMA Expression Requires Rho Activation and Calcium Release From Intracellular Stores**

It is known that S1P activates Rho and causes an increase in intracellular calcium. We tested a role for Rho and calcium in S1P2R-dependent SMA expression by using various inhibitors. Treatment of wild-type SMCs with C3 exotoxin (a Rho inhibitor), BAPTA-AM (calcium chelator), or thapsigargin (an inhibitor of the sarco-endoplasmic reticulum Ca2+/ATPase, SERCA) all prevented the S1P-dependent induction of SMA message and protein expression (Figure 4). In contrast, blockade of L-type VGCCs with nifedipine had no effect on SMA expression by S1P.

We next determined the contribution of S1P2R to activation of Rho and release of calcium by S1P. Based on the literature, S1P2R is the dominant S1P receptor to activate Rho but S1P3R might also contribute. In contrast, S1P3R is generally considered the primary S1P receptor responsible for the increase of intracellular calcium in response to S1P. In comparison to wild-type SMCs, activation of RhoA by S1P in S1P2R-null SMCs is insignificant (Figure 5A). As L-type VGCC-mediated calcium influx has recently been suggested to contribute to RhoA activation, we tested whether a calcium-dependent event is upstream of S1P-mediated activation of RhoA.
This is not the case as chelating calcium does not affect activation of RhoA by S1P (Figure 5B). Further, blockade of either SERCA by thapsigargin or L-type VGCCs by nifedipine had no effect on RhoA activity following S1P stimulation (Figure 5B).

To assess the contribution of S1P2R to the increase in intracellular calcium induced by S1P, we measured calcium transients in wild-type and S1P2R-null SMCs. On average, S1P2R-null cells reached only 25% of the S1P-mediated calcium increase observed in wild-type cells (Figure 6A), whereas, as expected, wild-type and S1P2R-null SMCs responded similarly to thrombin (Figure 6A). The S1P-induced calcium transients were abolished by BAPTA-AM and thapsigargin but not affected by nifedipine (Figure 6B), which is consistent with our observation that thapsigargin but not nifedipine inhibits S1P-induced expression of SMA (Figure 4). The effects of these drugs on KCl-stimulated calcium transients in SMCs have been investigated in control experiments, which confirmed the efficacy of nifedipine (supplemental Figure II). Further, we found that C3 exotoxin reduced the S1P-stimulated calcium release by approximately 60% suggesting that Rho regulates, at least in part, calcium transients induced by S1P (Figure 6B).

**Discussion**

We previously demonstrated that S1P2R-null carotid arteries respond to ligation injury with the formation of large neointimal lesions, whereas their wild-type littermates do not, suggesting that S1P2R inhibits neointimal growth.8 S1P2R blocks SMC migration by inhibiting activation of Rac.25,26 Although this mechanism is likely to contribute to the inhibitory effect of S1P2R on neointimal formation, it does not explain our finding that medial proliferation is much higher in injured S1P2R-null carotid arteries compared to wild-type arteries.8 An inhibitory effect of S1P2R on SMC proliferation in vitro has recently been demonstrated using the S1P2R antagonist, JTE-013.6 Given the previous observations in vitro that S1P induces expression of SMC differentiation genes via a Rho-dependent pathway9,10 and that

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**Figure 2.** SMA expression by S1P depends on S1P2R. Quiescent SMCs were stimulated with 1 μmol/L S1P. A, At 3 hours after stimulation, mRNA expression of CNN1, SMA, SM22α, SM-MHC, and MYOCDD was measured by qPCR. Data (mean±SD, n=4 to 5) are expressed as fold induction by S1P for wild-type and S1P2R-null SMCs, respectively. *P<0.05. B, At 24 hours after stimulation, total cell lysates were prepared and equal amounts (1 μg/lane) subjected to SDS-PAGE followed by Western blotting. Blots were probed with antibody against SMA, SM22α, and β-tubulin. Typical blots are shown for 2 independent isolates (a and b) for each cell type.

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**Figure 3.** S1P regulates enrichment of SRF and RNA polymerase II at the SMA gene in a S1P2R-dependent manner. At 15 minutes after stimulation, chromatin was prepared and analyzed for binding of serum response factor (SRF; A) and RNA polymerase II (Pol II; B) to CArG domains in the promoter and enhancer of SMA, as well as to a region approximately 6 Kb downstream of the start codon (control). Data (mean±SEM) are presented as percent of input; n=6 for wild-type (SRF, Pol II), n=5 for S1P2R-null (SRF, Pol II), and n=3 for all nonspecific antibody controls (rabbit IgG for SRF and mouse IgG-1 for Pol II).
S1P2R is the major contributor to Rho activation in response to S1P.19–22 We tested the hypothesis that S1P2R regulates expression of SMC differentiation genes after arterial injury. We measured mRNA expression of CNN1, SM22α, SM-MHC, and SMA after carotid injury in wild-type and S1P2R-null mice and found that at 2 days after injury, expression of all genes was decreased by approximately 50% in both animals. The only difference between wild-type and S1P2R-null animals was that re-expression of SMA at day 7 after injury only occurred in wild-type arteries (Figure 1A and supplemental Figure I). This was unexpected given our assumption that all SMC differentiation genes tested are similarly regulated by SRF and its cofactors of the myocardin/MRTF family. In vitro, S1P induces expression of SMA, SM22α, CNN1, and SM-MHC to different levels, and S1P2R seems to only promote the expression of SMA and SM22α.

Figure 5. Activation of RhoA by S1P depends on S1P2R. Quiescent SMCs (wild-type and S1P2R-null) were stimulated with 1 μmol/L S1P for 5 minutes before RhoA activity was measured. Data are expressed as fold stimulation over quiescent wild-type. A, Data are presented as mean±SD, n=3. B, Where indicated, wild-type cells were treated with BAPTA-AM (BA), nifedipine (Nif), or thapsigargin (TP) as described for Figure 4 before stimulation with S1P. Data are presented as percent expression with 100% measured in the presence of vehicle (mean±SD, n=3).

Figure 6. S1P releases calcium from intracellular stores in a S1P2R-dependent manner. Calcium transients were measured in quiescent wild-type and S1P2R-null SMCs after stimulation with 1 μmol/L S1P or 10 ng/mL thrombin and quantified by measuring peak height after setting the baseline to 1. Data are presented as mean±SD, n=10 to 12. *P<0.05 (drug-treated vs control, Bonferroni adjustment was applied). 

S1P regulates expression of multiple genes, including CNN1, SM22α, SM-MHC, and SMA, in response to arterial injury. In vitro, S1P activates RhoA and calcium release, which are mediated by S1P2R. These observations suggest that S1P2R is a key regulator of arterial remodeling after injury.
sion of SMA after injury, thereby limiting the potential of the injured artery to form an intima, but we cannot rule out other mechanisms.

To elucidate S1P2R-dependent signaling pathways that regulate SMA expression, we compared the responses of wild-type and S1P2R-null SMCs to S1P. We confirmed previous suggestions that S1P2R activates RhoA, and that RhoA is critical for SMA expression by S1P (Figures 4 and 5). In addition, we determined that release of calcium from intracellular stores is also required for S1P-mediated expression of SMA (Figure 4). Calcium transients after S1P stimulation have been previously reported and depending on cell type, different S1P receptors appear to be involved. Early studies using mouse embryonic fibroblasts lacking S1P2R, S1P3R, or both suggested that calcium increase induced by S1P is IP3-dependent and that S1P3R, but not S1P2R, is involved. In contrast, overexpression of individual S1P receptors in HeLa cells demonstrated the ability of S1P2R and S1P3R (but not S1P1R) to increase intracellular calcium after S1P stimulation. Our data in SMCs indicate S1P2R is the primary receptor responsible for S1P-induced increase of cytosolic calcium (Figure 6A). Consistent with their effects on SMA expression (Figure 4), thapsigargin but not nifedipine blocked the increase of intracellular calcium by S1P (Figure 6B). Moreover, blockade of Rho by C3 exotoxin was partially inhibitory suggesting that Rho regulates release of calcium from intracellular stores by S1P (Figure 6B). In endothelial cells, Rho has been shown to mediate an association of the IP3 receptor with the transient receptor potential channel (TRPC1) thereby stimulating calcium entry after store depletion. Whether such a mechanism exists in SMCs remains to be investigated.

To date, a calcium dependency for SMA expression has only been reported in KCl-treated SMCs. This study concluded that KCl-induced cell depolarization and the subsequent influx of calcium through L-type VGCCs regulates activation of RhoA. A similar mechanism has recently been proposed for S1P-induced activation of RhoA, based on the observation that nifedipine blocks both translocation of RhoA to the membrane and SRF enrichment at the SMA CarG domains in response to S1P. This further implies that nifedipine also blocks S1P-induced SMA expression, although these data were not presented. We tested the possibility that S1P might regulate SMA expression via L-type VGCCs operating upstream of RhoA by measuring S1P-induced RhoA activation and SMA expression in the absence and the presence of BAPTA-AM or nifedipine. Somewhat surprisingly, we found that nifedipine had no effect on RhoA activation or SMA expression (Figures 4 and 5), and we therefore conclude that L-type VGCCs are not required for S1P-induced SMA expression in mouse SMCs. Given this observation, we investigated whether calcium release from intracellular stores is stimulated by S1P and contributes to SMA expression. The SERCA-inhibitor thapsigargin blocked S1P-mediated SMA expression (Figure 4) as well as the increase of intracellular calcium (Figure 6D), but not the activation of RhoA by S1P (Figure 5B). This apparent discrepancy in S1P using different calcium stores to express SMA may be attributable to cell-type-specific properties as the above mentioned study was performed in rat aortic SMCs, whereas we used mouse carotid SMCs.

The mechanism by which calcium regulates SMA expression in SMCs is unknown. SRF is phosphorylated by calcium-dependent calmodulin kinase (CaMK) at multiple sites, which may directly regulate its activity. In cardiac myocytes, calcium/CaMK inhibits the association between SRF and a histone deacetylase thereby derepressing SRF activity. Epigenetic regulation of the SMA promoter has been shown, and it is an attractive possibility that calcium regulates SRF activity by the recruitment of histone modifying enzymes.

In summary, we provide evidence that S1P/S1P2R regulates SMA expression in arteries after injury. In vitro, the extent of induction of other SRF-dependent SMC differentiation genes by S1P greatly varies, and in vivo, SMA is the only SMC differentiation gene we found regulated by S1P2R. Although more work is necessary to define the role for S1P2R in the injury response, we believe that induction of SMA, and potentially additional SMC differentiation genes, contributes to the inhibition of neointimal growth by S1P2R.

We further demonstrate that S1P-mediated induction of SMA expression in vitro requires S1P2R-dependent activation of RhoA and release of calcium from intracellular stores.

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Disclosures

None.

References

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Supplement Material

Analysis of gene expression by Real time PCR
Total RNA was prepared from wild-type and S1P2R-null SMCs (Qiagen Mini Kit). RNA (1 µg) was reverse transcribed using the MultiScribe reverse transcriptase system (Applied Biosystems). TaqMan (Applied Biosystems) or SYBR green (Quantace) incorporation were utilized to determine gene expression. For RT-PCR using TaqMan probes: 75 ng of cDNA was combined with SensiMix (Quantace), and TaqMan primer probe mix. For RT-PCR using SYBR green, 75 ng of cDNA was combined with a commercially available mix containing polymerase, buffer, nucleotides and internal control (Sensimix, Quantace), SYBR green (Quantace) and primers (Table I). Cycle threshold numbers were determined using an ABI 7500 thermocycler (Applied Biosystems). Specificity of primers was verified by dissociation curves, and gene expression was normalized to expression of 18S RNA or GAPDH, respectively.

<table>
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<th>GENE</th>
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| S1P1R    | F - CTACTCCTGGTGCACGGACTGAA  
          | R - ACTCAGACAATGATCCAGGTCTCCT  
          | probe - 56-FAM/CGCCGCTGACCTCCGC/3IABkFQ |
| S1P2R    | F - AGTGACAAAGCTGCAGATG  
          | R - GCCAGTGTCATTAGCATAGAGAG  
          | probe - 56-FAM/TCTGGGTTGCTGACCCATCCTG/3IABkFQ |
| S1P3R    | F - ATGTACTTTTTTCTGGCAACTTG  
          | R - ACGTCTTTCCCTGCGGACATA  
          | probe - 56-FAM/TGGCCGCGCATAGCATAACAGGTCAAT/3IABkFQ |
| 18S      | F - CGGACAGGATAGAGATTG  
          | R - CAAATCGCTCAACCAACTAA  
          | probe - 56-FAM/CACCACCACC CGGAATCG/3IABkFQ |
| SMA      | F - TACATGGCGGGGACATGTGAA  
          | R - CCGATAGAACACGGCATCATCA |
| CNN1     | F - ATGCCCCAGACCTGGCTCAAA  
          | R - ACTGCAGATGGCGCAACCAACA |
| SM22α    | F - CAACAAGGGTCCATCTACAGG  
          | R - ATCTGGGCTGCCCTACATCA |
| SM-MHC   | F - AAGCTGCGCTAGAGGTCA  
          | R - GCCGATTAAGCCTGGTCTGAG |
| myocardin | F - ACACCTGCGGCTGAACAAC  
          | R - GCGGTATTAAGCCTTGACGCC |
| GAPDH    | F - GCCCAAGATGCCCTTCAGT  
          | R - CATCCACTTTGTGCTGCAAG |

Table I: Primer and probe sequences for Real time PCR
Western blot analysis
Frozen arteries were pulverized using a mortar and pestle. Tissue powder was extracted in lysis buffer (Cytoskeleton). Extracts were cleared by centrifugation prior to determining protein concentration using Precision Red protein detection reagent (Cytoskeleton). SMCs were plated into 6-well plates (100,000 cells/well) and next day, media was changed to serum-free media. After 2-3 days, cells were extracted with SDS-polyacrylamide gel electrophoresis (SDS-PAGE) sample buffer. Equal amounts of protein were subjected to SDS-PAGE followed by Western blotting. Blots were probed with primary antibody overnight at 4°C and then developed with ECL (GE Healthcare). Equal loading of protein was confirmed by re-probing blots for β-actin or β-tubulin.

Chromatin immunoprecipitation (ChIP) assay
Cell Fixation and Lysis: Quiescent or stimulated (1 µmol/L S1P for 15 minutes) SMCs (10^6 cells) were fixed at room temperature by the addition of formaldehyde to the media (final concentration: 1.42%). After 45 min, formaldehyde was quenched with 125 mmol/L glycine for 5 minutes. Cells were harvested into ice-cold PBS, washed twice with PBS and lysed in ChIP immunoprecipitation (IP) buffer (150 mmol/L NaCl, 50 mmol/L Tris-HCl pH 7.5, 5 mmol/L EDTA, 0.5% v/v NP-40, 1% v/v Triton X-100, 1 mmol/L DTT, 10 µg/mL leupeptin, 10 mmol/L β-glycerophosphate, 10 mmol/L NaF, 0.1 mmol/L Na_3VO_4).
Chromatin Preparation: The nuclear pellet was isolated by centrifugation and resuspended to the equivalent of 2 million cells per 100 µL of IP buffer and chromatin sheared using the Biorupter (a sealed-type sonicating water bath) set to medium intensity with 2 rounds of 15 minute sonication pulses. The remaining insoluble material was removed by centrifugation. Immunoprecipitation: The supernatant was diluted to the equivalent of 5 million cells/mL with IP buffer. An aliquot of 0.2 mL was combined with antibody (2 µg SRF, 1.5 µg Pol II, 2 µg rabbit IgG or 1.5 µg normal mouse IgG-1κ) and incubated at 4°C in an ultrasonic water bath (Branson) for 15 min. Following removal of non-specific aggregates by centrifugation, 40 µL of a 1:1 slurry of protein A sepharose beads and IP buffer without inhibitors (DTT, leupeptin, β-glycerophosphate, NaF, and Na_3VO_4) was added to samples. The mixture was incubated for 1 hr at 4°C with constant agitation, before the beads were collected by centrifugation and washed 5 times with IP buffer without inhibitors.
DNA isolation: Beads were mixed with 100 µL of 10% Chelex-100 (w/v in water, Bio-Rad), 20 µg of proteinase K (Qiagen), incubated at 60°C for 20 min in a thermal shaker (Eppendorf), and finally boiled for 10 minutes to elute DNA. The beads were removed by centrifugation and the supernatant subjected to qPCR analysis. See Table II for primer sequences.

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<td>intronic CArG</td>
<td>F - CGGTGCAATTCACAAAGCAG&lt;br&gt; R - CCCGTGTGGTTTGCAACTCTT</td>
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<tr>
<td>+6kB negative control</td>
<td>F - TTCCAGGACCTTTTGCATCC&lt;br&gt; R - CCGGTAGGGTTCAAGTGGTG</td>
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Table II: Primer sequences for ChIP assays
S1P2R-null arteries express less SMA compared to wild-type arteries after injury (Figure I). S1P2R-null and wild-type mice underwent ligation injury of the left carotid artery. At the indicated time points, arteries were harvested; right arteries served as controls (0 days). (A) Protein was subjected to Western blotting analysis for expression of SMA, SM22α, and β-actin. This experiment was repeated with similar results. (B) SMA expression at day 7 after injury was quantified (mean +/- S.E.M. (n=3). *P<0.05

Effect of nifedipine, BAPTA-AM and thapsigargin on KCL-induced calcium transients in SMCs (Figure II). As positive control for nifedipine, we confirmed that the drug blocks KCL-induced calcium transients. These control experiments included BAPTA-AM and thapsigargin. As expected, BAPTA-AM completely prevented KCL-mediated calcium transients, and as has been reported previously, thapsigargin was also inhibitory. Quiescent wild-type SMCs were loaded with Fluo4 calcium indicator dye and pretreated with BAPTA-AM, nifedipine and thapsigargin, as described for Figure 4, before stimulation with 60 mmol/L KCl. SMCs without pretreatment served as controls. Changes in intracellular calcium levels were recorded using confocal microscopy. Typical calcium transients are shown for nifedipine (A), BAPTA-AM (B) and thapsigargin (C). All experiments have been repeated with a different cell isolate and yielded similar results.
