Tetrahedron 73 (2017) 2290–2304

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Stereoselective addition of Grignard reagents to (2-methyl-5-*tert*-butyl)phenyl 1-thio-β-D-ribopentodialdo-1,4-furanoside derivative

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ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form
4 March 2017
Accepted 6 March 2017
Available online 9 March 2017
Dedicated to Prof. Dr. Weiyong Ma

Keywords:
Nucleophilic addition
Stereoselective reaction
Grignard reagents
5-*C*-Substituted ribofuranoside
Mosher ester

ABSTRACT

Addition of a wide range of Grignard reagents to acetone protected (2-methyl-5-*tert*-butyl)phenyl 1-thio-β-D-ribopentodialdo-1,4-furanoside **3b** produced useful 5(*R*)—*C*-substituted products with moderate to good yields, and moderate to perfect stereoselectivities, with no need of additives. n.O.e. Analysis of **3b** showed that 1-*S*-aryl group could contribute to the stereoselectivity of addition reaction. The stereochemistry of 4 representative 5-*C*-substituted ribofuranoside products was further confirmed by NMR study of corresponding Mosher esters, by chemical derivatization, or by single crystal study.

1. Introduction

Enantiomerically pure 5-*C*-substituted ribofuranoside (Scheme 1, structure **1**) is useful building block for organic synthesis.[1] This type of compounds is often prepared from the addition reaction between ribopentodialdo-1,4-furanosides (Scheme 1, structure **2**) and organolithium,[2a] organomagnesium,[2a-f] or organotin reagents.[2g,h] These organometallic reagents often attack from the *Re*-face (according to the conformation in structure **2**) of the 5-aldehyde, yielding unsatisfactory enatioselectivity for most of the ribose substrates and organometallic reagents. Recently, arylzincs were found good nucleophile to ribopentodialdo-1,4-furanosides,[1d,3] and constantly produced good to excellent stereoselectivity in the addition reaction. Because the organozinc reagents were prepared by metal exchange reaction using organic boronic acids, the nucleophile is reportedly limited to aryl groups. Interestingly, the attack of the arylzinc reagents was on the *Si*-face of the aldehyde (according to the conformation in structure **2**), and the stereochemistry was explained by the Zn-chelation model.[1d] Clearly, there was a lack of general method to prepare 5-*C*-substituted ribofuranoside **1** from structure **2** with both features of broad nucleophile scope and good stereoselectivity.

During our study of carbohydrate chemisty, 5-*C*-substituted ribofuranosides were required, too. Instead of using the known substrate **3a** for the addition reaction, we prepared compound **3b** as the substrate, initially because odorless 5-(*tert*-butyl)-2-methylbenzenethiol is a preferred reagent. After several experimentations, compound **3b** appeared to be a great substrate for the enantioselective addition reactions with a wide range of Grignard reagents, with no need of additives. The yield and enantioselectivity were generally satisfying, especially with alkyl magnesium reagents. The stereochemistry of 4 representative 5-*C*-substituted ribofuranoside products was further confirmed by NMR study of corresponding Mosher esters, by chemical derivatization, or by single crystal study. It was found that in all cases, the Grignard reagents approaches from the *Re*-face of the 5-aldehyde group (according to the conformation in structure **2**). The details of the work will be reported herein.

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http://dx.doi.org/10.1016/j.tet.2017.03.013
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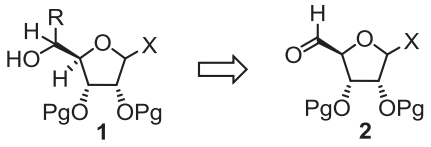
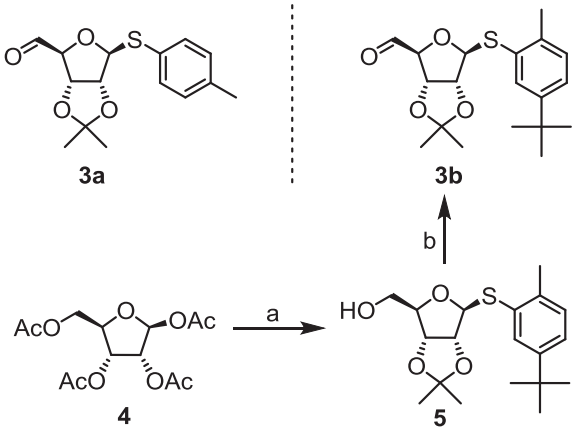


Scheme 1. Typically, 5-*C*-substituted ribofuranoside (**1**) was prepared from ribopentodialdo-1,4-furanosides (**2**) and organometallic reagents.

2. Results and discussion

From compound **4**, compound **3b** was prepared through 3 consecutive steps, including *S*-glycosylation, deacylation, and acetonide protection, without purification of intermediates. The yield of the *beta*-anomer **5**[4] was 45% for 3 steps, demonstrating that both the stereoelectivity of glycosylation step, and the conversion of each step were good. Next, the free 5-OH on compound **5** was oxidized with Dess-Martin reagent to the desired aldehyde substrate **3b** with 77% yield (Scheme 2).

Substrate **3b** was reacted in THF with methylmagnesium bromide at −78 °C, and it was found that the yield of 5(*R*)-isomer **6b** was good and the stereoselectivity excellent (The stereochemistry of the addition product was hypothesized at the stage, and confirmed later in this work by different studies). To separate the minor 5(*S*)-isomer **6a**, we performed another addition reaction at 0 °C. The stereochemical outcome decreased to 1:8.0, but was still good enough for synthetic purpose (Table 1, Entry 1). Next, ethyl and isopropyl Grignard reagents were tested and showed for both cases reduced yields, although which were compensated by the perfect stereoselectivity observed for products **7** and **8**, even at 0 °C (Table 1, Entry 2 and 3). In the case of entry 3, the compromised yield was partially due to the reduction of **3b** to **5**. From vinylmagnesium bromide (Table 1, Entry 4), the diastereomeric ratio of products **9a** and **9b** was 1:10.1 at −78 °C, and 1:5.3 at 0 °C. Although the stereoselectivity was lower than that of the alkyl cases, it was still synthetically useful. Using isopropenylmagnesium bromide (Table 1, Entry 5) as nucleophile, the stereoselectivity decreased significantly, but the yields of **10a** and **10b** were similar to that in vinyl cases. Next, 1-propynylmagnesium bromide showed very low reactivity in the addition reaction (Table 1, Entry 6). Even at 0 °C, large amount of remaining starting material **3b** was recovered. Meanwhile, the highly reactive allylmagnesium chloride gave moderate results in terms of both yields and stereoselectivity, to products **12a** and **12b** (Table 1, Entry 7). In entries 8 and 9, phenylmagnesium bromide and *p*-fluorophenylmagnesium bromide were reacted with **3b** to give good yields and moderate stereoselectivity for products **13a**/**b** and **14a**/**b** respectively. With the increase of steric hindrance at the nucleophilic center (Table 1, Entry 10), *o*-tolylmagnesium bromide again showed perfect stereoselectivity, without sacrificing the yield of product **15** too much. For most cases, the nucleophilic addition on compound **3a** gave yields above 60% and stereoselectivity above 1:4.0, with a broad spectrum of Grignard reagents and very simple experimental setting, as no additives was needed. Meanwhile, in all cases, the yields and stereoselectivities were weakly affected by the temperature change. Thus, the internal factors in compound **3b** that control the course of stereoselective addition must be strong.



Scheme 2. Preparations of aldehyde substrate **3b**. Reaction conditions: a) 2-methyl-5-*tert*-butyl-thiophenol, BF_3 etherate, DCM; then methanolic ammonia; then $Me_2C(OMe)_2$, acetone, *p*-TsOH hydrate, 45% from compound **4**. b) Dess-Martin periodinane, DCM, 77%.

To understand the robust factors in compound **3b** that dominated the addition reactions, n.O.e. effect was measured at room temperature in $CDCl_3$. As shown in Fig. 1, interactions between H-5′ and H-5, as well as interactions between 2′−CH_3 and H-1 indicated the close contact between 1-*S*-phenyl group and 4-formyl group. Meanwhile, one of the acetonide methyl groups showed correlation with H-2 and H-3, and another one interacted with H-1 and H-4. A simple modeling study[5] (Fig. 1) further visualized the n.O.e.. As shown in Fig. 1, the *Si*-face of the 4-formyl group (according to the conformation in this image) has been shielded by *t*-Bu group, rendering the nucleophilic attack from this side difficult. Also, the *Re*-face attack agreed with polar Felkin-Ahn model, as the nucleophile should approach from a direction close to C4−O6 σ* bond.

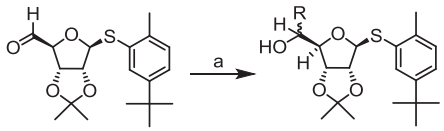
The experimental setting of the addition reaction was already very simple, the spectrum of Grignard reagent was broad, the yield of most products was good, and the stereoselectivity was generally suitable for preparation purpose. Therefore, we did not continue optimize the addition reaction condition. Instead, since the stereochemistry of most products was not clarified in history, we feel the necessity to undertake this task.

Thus, Mosher esters[6,7] were prepared from representative substrates, including methyl diastereomeric pair **6a**/**b**, vinyl diastereomeric pair **9a**/**b**, allyl diastereomeric pair **13a**/**b**, and phenyl diastereomeric pair **14a**/**b**, via Mosher acid chlorides **16a**/**b**.

As shown in Table 2: From compound **6a**, esters **6aR** and **6aS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively. From compound **6b**, esters **6bR** and **6bS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively, too. In Table 2, equation 1, H^3 in **6aR** was shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **6aS**. Due to a similar shielding effect, 5-$C\underline{H}_3$ in **6aS** shifted upfield relative to that in **6aS**. The chemical shift difference of H^4 in **6aR** and of H^4 in **6aS** is too small to be considered. Since the sugar (as the larger group C-5) -phenyl (as the larger group on C-2″) interaction was more energetically disfavored, $C\underline{F}_3$ in **6aR** was forced into the shielding zone of the carbonyl group, thus showing an upfield shift in ^{19}F NMR relative to that in **6aS**. Meanwhile, when being compared with the yield of **6aS** in the esterification step, the particularly low yield of **6aR** could reflect the disfavored interaction between the sugar and phenyl ring on C-2″), too. Analogously, as demonstrated in Table 2, equation 2, H^3 and H^4 in **6bS** were shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **6bR**. Due to the similar shielding effect, 5-$C\underline{H}_3$ in **6bR** shifted upfield relative to that in **6bS**. Because of the energetically disfavored interaction between the sugar (as the larger group C-5) and phenyl ring (as the larger group on C-2″), $C\underline{F}_3$ in **6bS** was forced into the shielding zone of the carbonyl group, thus showing an upfield shift in ^{19}F NMR relative to that of **6bR**. Thus, all major chemical shift value change supported the proposed stereochemistry of **6a** and **6b**.

As shown in Table 3: From compound **9a**, esters **9aR** and **9aS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher

Table 1
Addition of Grignard reagents to aldehyde **7**.[a]



3b **6a,b-15**

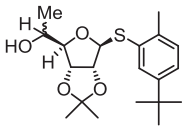
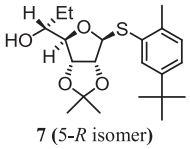
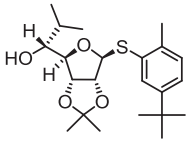
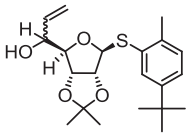
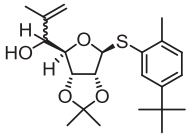
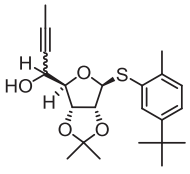
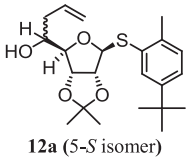
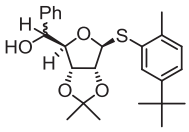
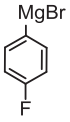
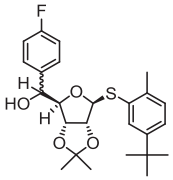
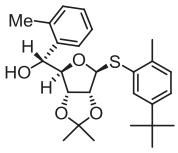
No	RMgx	Products[b]	Yield[c] @ −78 °C (5-*S*:5-*R*)[d]	Yield[c] @ 0 °C (5-*S*:5-*R*)[d]
1	MeMgBr in ether	 **6a** (5-*S* isomer) **6b** (5-*R* isomer)	92% (1:14.3)	92% (1:8.0)
2	EtMgBr in THF	 **7** (5-*R* isomer)	65% (only 5-*R* isomer)	68% (only 5-*R* isomer)
3	*i*-PrMgBr in THF	 **8** (5-*R* isomer)	59%[e] (only 5-*R* isomer)	61%[f] (only 5-*R* isomer)
4	 in THF	 **9a** (5-*S* isomer) **9b** (5-*R* isomer)	76% (1:10.1)	71% (1:5.3)
5	 in THF	 **10a** (5-*S* isomer) **10b** (5-*R* isomer)	76% (1:2.9)	78% (1:1.5)
6	 in THF	 **11**	No product isolated.[g]	No product isolated.[g]
7	 in THF	 **12a** (5-*S* isomer) **12b** (5-*R* isomer)	62% (1:5.0)	83% (1:5.3)

Table 1 (*continued*)

No	RMgx	Products[b]	Yield[c] @ −78 °C (5-*S*:5-*R*)[d]	Yield[c] @ 0 °C (5-*S*:5-*R*)[d]
8	PhMgBr in THF	 **13a** (5-*S* isomer) **13b** (5-*R* isomer)	84% (1:4.0)	79% (1:2.1)
9	 in THF	 **14a** (5-*R* isomer) **14b** (5-*S* isomer)	89% (1:2.2)	87% (1:3.5)
10	 in THF	 **15** (5-*R* isomer)	73% (only 5-*R* isomer)	79% (only 5-*R* isomer)

[a] Reaction conditions: a) Grignard reagents (3 equiv.), THF.
[b] The suffix "**a**" or "**b**" in product numbers are in accordance with the order of chromatography peaks. Thus, "**a**" or "**b**" does not correspond to the stereodescriptor "*R*-" or "*S*-".
[c] Chromatography separation yields.
[d] All diastereoisomers were separated by flash chromatography, and the ratio was based on separation yield.
[e] With 9% of reduction product **6** separated.
[f] With 19% of reduction product **6** separated.
[g] Unreacted starting material **3b** was recovered.

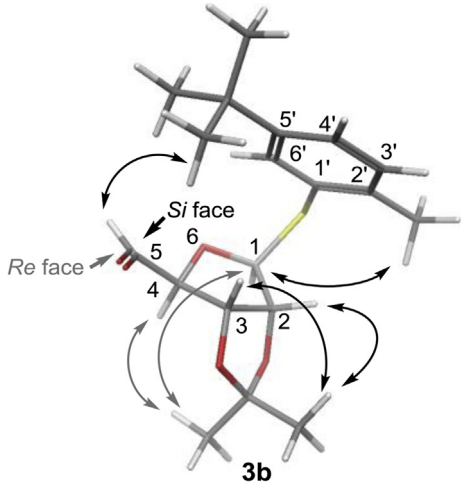


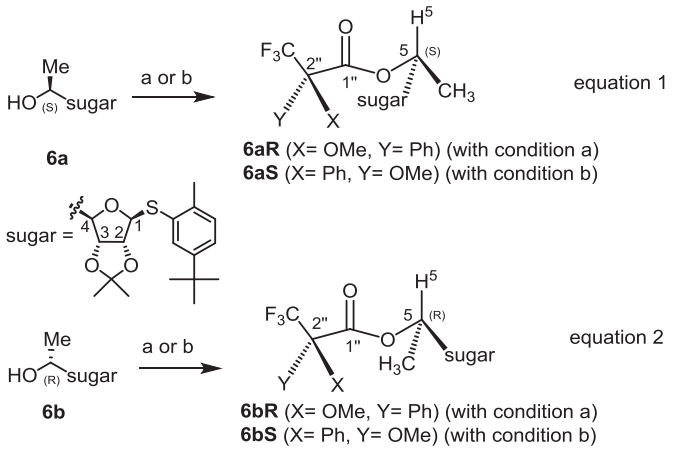
Fig. 1. n.O.e. observed for compound **3b**.

acid chloride (**16b**) respectively. From compound **9b**, esters **9bR** and **9bS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively, too. In Table 3, equation 1, according to the proposed structure and conformation, H^3 in **9aR** was shielded by the phenyl ring on C-2″ and should shift upfield relative to that in **9aS**, nevertheless opposite result was recorded. Due to a similar shielding effect, CH_2=C<u>H</u> and C<u>H_2</u>=CH in **9aS** should shift upfield relative to that in **9aS**. However, opposite result was recorded again for C<u>H_2</u>=CH, while the shift change for CH_2=C<u>H</u> was too small to be considered. Also, the chemical shift difference of H^4 in **9aR** and of H^4 in **9aS** is too small to be considered. Since the sugar (as the larger group C-5) -phenyl (as the larger group on C-2″) interaction is more energetically disfavored, C<u>F_3</u> in **9aR** was forced into the shielding zone of the carbonyl group, and should give an upfield shift in ^{19}F NMR relative to that in **9aS**. However, inversed shift change was observed one more time. Analogously, as demonstrated in Table 3, equation 2, all major shift difference for H,[3] CH_2=C<u>H</u>, C<u>H_2</u>=CH, and C<u>F_3</u> in **9bR** and **9bS** were inconsistent (red values in Table 3) to the proposed structure and conformation. Only the chemical shift difference of H^4 in **9bR** and **9bS** was in accord with prediction. In addition, comparison of H^5 in **9bR** and **9bS** revealed significant change of −0.36 ~ −0.23, indicating that the conformations of **9bR** and **9bS** may not be ideal for Mosher ester analysis.

As NMR analysis of Mosher ester derivatives **9aR**, **9aS**, **9bR**, and **9bS** questioned the proposed stereochemistry of **9a** and **9b**, we had to seek other method to validate the structure of **9a** and **9b**. To this end, major diastereomer **9b** was subjected to regular hydrogenation condition at RT and 1 atm with excessive 10% Pd/C. Interestingly, 1-sulfide remained intact while the vinyl susbstitution was reduced to ethyl group (Scheme 3). The proton NMR of the product was found identical to that of compound **7**. As the hydrogenation condition was neutral on pH scale, epimerization of 5-OH at the allylic position was not likely. Thus, we concluded that the proposed structure of **9a** and **9b** were correct and Mosher ester analysis was not applicable on these two compounds.

As shown in Table 4: From compound **12a**, esters **12aR** and **12aS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively. From compound **12b**, esters **12bR** and **12bS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively, too. In Table 4, equation 1, H^3 and H^4 in **12aR** were shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **12aS**. Due to a similar

Table 2
Determination of absolute stereochemistry on Mosher's acid derivatives **6aR**, **6aS**, **6bR**, and **6bS**.[a]



Selected NMR data (δ) of 6a derivatives		
6aR (38% from 6a)[b]	6aS (88% from 6a)[b]	Δδ
H^3 = 4.13	H^3 = 4.51	−0.38
H^4 = 4.17	H^4 = 4.13	+0.04
H^5 = 5.19	H^5 = 5.30	−0.11
5-CH_3 = 1.45	5-CH_3 = 1.35	+0.10
CF_3 = −71.92	CF_3 = −71.40	−0.52
Selected NMR data (δ) of **6b** derivatives		
6bR (50% from **6b**)[b]	**6bS** (82% from **6b**)[b]	Δδ
H^3 = 4.74–4.65	H^3 = 4.50	+0.24 ~ +0.15
H^4 = 4.08	H^4 = 4.03	+0.05
H^5 = 5.47	H^5 = 5.47–5.39	0 ~ +0.08
5-CH_3 = 1.29	5-CH_3 = 1.37	−0.08
CF_3 = −71.43	CF_3 = −71.50	+0.07

[a] Reaction conditions: a) (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16a**), pyridine, MeCN; b) (*S*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16b**), pyridine, MeCN.
[b] Chromatography separation yields.

shielding effect, CH_2=CH−CH_2, CH_2=CH−CH_2, and CH_2=CH−CH_2 in **12aS** shifted upfield relative to that in **12aS**. Since the sugar (as the larger group C-5) -phenyl (as the larger group on C-2″) interaction was more energetically disfavored, CF_3 in **12aR** was forced into the shielding zone of the carbonyl group, thus showing an upfield shift in ^{19}F NMR relative to that in **12aS**. Meanwhile, the particularly low yield of **12aR** in the esterification step relative to the yield of **12aS** could reflect the disfavored interaction between the sugar and phenyl ring on C-2″), too. Analogously, as demonstrated in Table 4, equation 2, H^3 and H^4 in **12bS** were shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **12bR**. Due to a similar shielding effect, CH_2=CH−CH_2, CH_2=CH−CH_2, and CH_2=CH−CH_2 in **12bR** shifted upfield relative to that in **12bS**. Because of the energetically disfavored interaction between the sugar (as the larger group C-5) and phenyl ring (as the larger group on C-2″), CF_3 in **12bS** was forced into the shielding zone of the carbonyl group, thus showing an upfield shift in ^{19}F NMR relative to that of **12bR**. Thus, all major chemical shift change supported the proposed stereochemistry of **12a** and **12b**.

As shown in Table 5: From compound **13a**, esters **13aR** and **13aS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively. From compound **13b**, esters **13bR** and **13bS** were prepared with (*R*)-Mosher acid chloride (**16a**) and (*S*)-Mosher acid chloride (**16b**) respectively, too. In Table 5, equation 1, H^3 in **13aR** was shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **13aS**. The chemical shift difference of H^4 in **13aR** and of H^4 in **13aS** was too small to be considered. The proton signals of 2″-phenyl group and 5-phenyl group could not be assigned due to overlapping. In Table 5, equation 1, according to the proposed structure and conformation, we considered that chemical shift of 2″−CH_3O could be used to probe the C5 stereochemistry as it should be affected by 5-phenyl group. Unfortunately, the chemical shift difference of CH_3O in **13aR** and of H^4 in **13aS** was too small to be considered useful. Since the sugar (as the larger group C-5)-phenyl (as the larger group on C-2″) interaction was more energetically disfavored, CF_3 in **13aR** was forced into the shielding zone of the carbonyl group, and should give an upfield shift in ^{19}F NMR relative to that in **13aS**. However, inversed shift change was observed (red values in Table 5). In Table 5, equation 2, H^3 in **13bR** was shielded by the phenyl ring on C-2″ and shifted upfield relative to that in **13bS**. Although according to the proposed structure and conformation, H^4 in **13bR** was also shielded by the phenyl ring on C-2″ and should shift upfield relative to that in **13bS**, opposite result was recorded (red values in Table 5). Chemical shift of CH_3O in **13bR** indeed moved downfield relative to the chemical shift of CH_3O in **13bS**, presumably because of the shielding of 5-phenyl ring. Due to the energetically disfavored interaction between the sugar (as the larger group C-5) and phenyl ring (as the larger group on C-2″), CF_3 in **13bS** was forced into the shielding zone of the carbonyl group, thus showing an upfield shift in ^{19}F NMR relative to that of **13bR**. Nevertheless, inversed shift change was recorded again (red values in Table 5). Thus, Mosher ester analysis for compounds **13a** and **13b** was inconclusive.

To validate the proposed stereochemistry of **13a** and **13b**, major diastereomer **13b** was oxidized with *m*CPBA first to sulfoxide, which was an oil if separated, and then to sulfone **17** in one pot. Compound **17** was a solid and could be converted into single crystal in TBME and petroleum ether. X-Ray analysis of crystalline **17**[8] showed that the absolute stereochemistry of C5 was *R* unambiguously (Scheme 4), further indicated that Mosher ester analysis was not applicable on compounds **13a** and **13b**.

It is known that sterically congested system could render Mosher ester analysis less effective.[9] In this work, through the data collected for the vinyl substituted **9aR**, **9aS**, **9bR**, and **9bS**, as well as for the phenyl substituted **13aR**, **13aS**, **13bR**, and **13bS**, we have found that the group with *pi*-electrons directly connected to the chiral center in question could interrupt Mosher ester analysis, too.

3. Conclusion

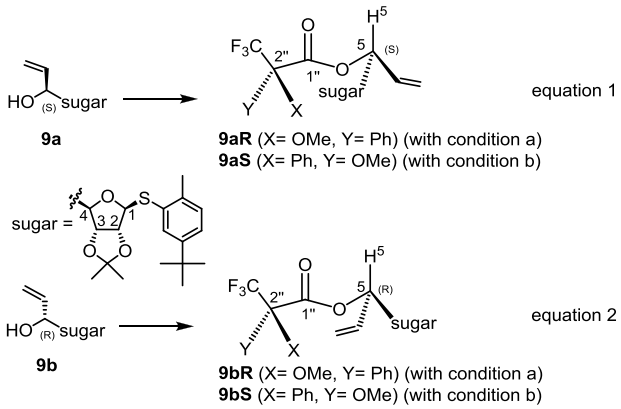
Addition of alkyl, vinyl, allyl, and aryl Grignard reagents to acetone protected (2-methyl-5-*tert*-butyl)phenyl 1-thio-*β*-D-ribopentodialdo-1,4-furanoside **3b** produced useful 5(*R*)−*C*-substituted products with moderate to good yields, and moderate to perfect stereoselectivities. As the addition reaction was carried out in THF with no need of additives, the high stereoselectivity was attributed to the conformation arrangement of **3b**. The stereochemistry of 4 representative 5-*C*-substituted ribofuranoside products was further confirmed by NMR study of corresponding Mosher esters, by chemical derivatization, or by single crystal study. During the study of the C5-stereochemistry, the group with *pi*-electrons directly connected to the chiral center in question was found interrupting Mosher ester analysis. This suggests that Mosher ester analysis of other allylic or benzylic alcohols should be made with caution, too.

4. Experimental section

4.1. General

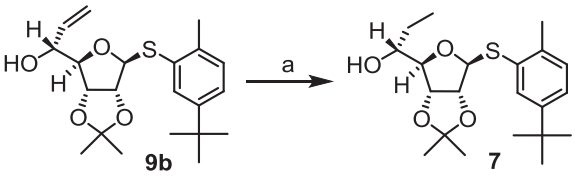
All solvents were dried and purified prior to use: Et_2O and THF

Table 3
Determination of absolute stereochemistry on Mosher's acid derivatives **9aR**, **9aS**, **9bR**, and **9bS**.[a]



Selected NMR data (δ) of **9a** derivatives		
9aR (32% from **19a**)[b]	**9aS** (57% from **9a**)[b]	Δδ
H^3 = 4.69	H^3 = 4.58	+0.11
H^4 = 4.19	H^4 = 4.23	-0.04
H^5 = 5.84 ~ 5.72	H^5 = 5.63	+0.21 ~ +0.09
CH_2=C<u>H</u> = 5.84 ~ 5.72	CH_2=C<u>H</u> = 5.74	+0.10 ~ -0.02
C<u>H_2</u>=CH = 5.28	C<u>H_2</u>=CH = 5.43	-0.15
C<u>F_3</u> = -71.34	C<u>F_3</u> = -71.52	+0.18
Selected NMR data (δ) of **9b** derivatives		
9bR (64% from **9b**)[b]	**9bS** (51% from **9b**)[b]	Δδ
H^3 = 4.33	H^3 = 4.56	-0.23
H^4 = 4.29	H^4 = 4.17	+0.12
H^5 = 5.45	H^5 = 5.91 ~ 5.78	-0.36 ~ -0.23
CH_2=C<u>H</u> = 5.94	CH_2=C<u>H</u> = 5.91 ~ 5.78	+0.03 ~ +0.16
C<u>H_2</u>=CH = 5.58	C<u>H_2</u>=CH = 5.37	+0.21
C<u>F_3</u> = -71.96	C<u>F_3</u> = -71.38	-0.58

[a] Reaction conditions: a) (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16a**), pyridine, MeCN; b) (*S*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16b**), pyridine, MeCN. [b] Chromatography separation yields.



Scheme 3. Hydrogenation of compound **9b** yielded compound **7**. Reaction conditions: a) H_2, MeOH, excessive 10% Pd/C, 1 atm, RT, 8 h, 80%.

were distilled from potassium, and DCM was distilled from CaH_2. All other commercially available reagents were used as received. All moisture sensitive reactions were performed under N_2 (ca. +1.1 bar) in heating-gun (500–600 °C)/vacuum dried glassware sealed with rubber septa. Flash chromatography was performed on silica gel (300–400 mesh ASTM), and monitored by thin layer chromatography (TLC) on HSGF-254 (10–40 μm) TLC plates. NMR data were collected on a *Varian* Mercury-300 High Performance Digital FT-NMR, a *Varian* Mercury-400 High Performance Digital FT-NMR, a Bruker Ultrashield 500 NMR, or an Agilent 1260 Prospekt 2 Bruker Ascend 600 NMR. Spectra from solutions in $CDCl_3$ (δ_C = 77.0 ppm) are calibrated relative to TMS (δ_H = 0.00 ppm). HRMS were carried out on a *Thermo Finnigan* MAT-95 spectrometer (for EI), or on a *Waters*, Q-Tof Ultima Global spectrometer (for ESI). Melting points were measured on an uncorrected SGW X-4 micro melting point apparatus. HPLC analysis was performed on a Gilson HPLC system (306 pump, UV/vis-156 Detector, 215 liquid handle) with a YMC-ODS column (4.6 × 50 mm, 5 μm). HPLC conditions: solvent A = H_2O containing 0.1% (v/v) TFA, solvent B = MeCN containing 0.1% (v/v) TFA; flow rate = 2.5 mL/min; Gradient (B%): 0–0.5 min (4% isostatic), 0.5–4.5 min (4%–95%), 4.5–6.1 min (95% isostatic), 6.1–6.3 min (95%–4%), 6.3–8.0 min (4% isostatic); peaks were identified at 254 nm and 214 nm.

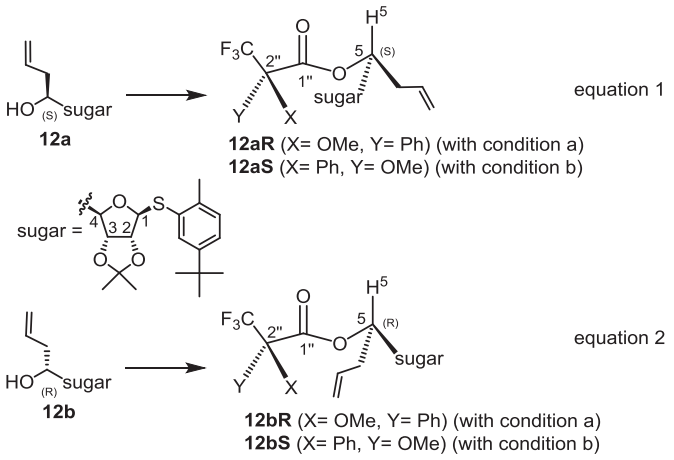
4.2. Experimental

4.2.1. ((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)methanol (**5**)

A solution of commercially available compound **4** (20 g, 62.8 mmol, 1 equiv.) in DCM (150 mL) was treated with 5-(*tert*-butyl)-2-methylbenzenethiol (10.76 g, 59.7 mmol, 0.95 equiv.) and BF3 etherate (9.8 g, 62.8 mmol, 1 equiv.), and stirred at RT for 4 h. The reaction was quenched with sat. aq. $NaHCO_3$ and extracted with DCM. Combined organic phases were washed with brine and concentrated to give a light yellow oil (34.0 g).

A solution of above-mentioned light yellow oil (34.0 g) in MeOH (200 mL) was treated with NaOMe (2 g, 37 mmol) and stirred at RT for 2 h. The reaction was quenched by sat. aq. NH_4Cl, concentrated,

Table 4
Determination of absolute stereochemistry on Mosher's acid derivatives **12aR**, **12aS**, **12bR**, and **12bS**.[a]



Selected NMR data (δ) of 12a derivatives		
12aR (19% from 12a)[b]	12aS (62% from 12a)[b]	Δδ
H^3 = 4.05	H^3 = 4.48	−0.43
H^4 = 3.92	H^4 = 4.20	−0.28
H^5 = 5.14	H^5 = 5.34–5.25	−0.20 ~ −0.11
CH_2=CH−CH_2-a = 2.68	CH_2=CH−CH_2-a = 2.56	+0.12
CH_2=CH−CH_2-b = 2.57	CH_2=CH−CH_2-b = 2.39	+0.18
CH_2=CH−CH_2 = 5.79	CH_2=CH−CH_2 = 5.66	+0.13
CH_2=CH−CH_2 = 5.18	CH_2=CH−CH_2− = 5.07	+0.11
CF_3 = −71.66	CF_3 = −71.10	−0.56
Selected NMR data (δ) of **12b** derivatives		
12bR (31% from **12b**)[b]	**12bS** (19% from **12b**)[b]	Δδ
H^3 = 4.74–4.65	H^3 = 4.51	+0.23 ~ +0.14
H^4 = 4.16	H^4 = 4.11	+0.05
H^5 = 5.51	H^5 = 5.52	−0.01
CH_2=CH−CH_2-a = 2.47	CH_2=CH−CH_2-a = 2.58	−0.11
CH_2=CH−CH_2-b = 2.34	CH_2=CH−CH_2-b = 2.39	−0.15
CH_2=CH−CH_2 = 5.60	CH_2=CH−CH_2 = 5.72	−0.12
CH_2=CH−CH_2− = 4.96	CH_2=CH−CH_2− = 5.07	−0.11
CF_3 = −71.14	CF_3 = −71.25	+0.11

[a] Reaction conditions: a) (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16a**), pyridine, MeCN; b) (*S*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16b**), pyridine, MeCN.
[b] Chromatography separation yields.

and extracted with a mixture of DCM and MeOH (DCM: MeOH = 10:1, *v/v*). The organic phase was washed with sat. aq. $NaHCO_3$ and brine and concentrated to give a light yellow oil (22.0 g).

A solution of above-mentioned light yellow oil (22.0 g) in acetone (160 mL) was treated with $Me_2C(OMe)_2$ (40 mL, 325.3 mmol) and *p*-TSA hydrate (2 g, 11.6 mmol) and stirred at RT for 4 h. The reaction was quenched by sat. aq. $NaHCO_3$, concentrated, and extracted with DCM. The organic phase was washed with brine, concentrated, and purified with flash chromatography (on silica gel with 60–90 °C petroleum ether: EtOAc = 10:1–5:1) to give product **5** (colorless oil, 10 g, 28.4 mmol, 45% based on compound **4**). Compound **5**: R_f 0.36 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.07 min; $[\alpha]_D = -76$ (20 °C, c = 0.71, $CDCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.60 (m, 1H, H^6-thiophenol), 7.28–7.22 (m, 1H, H^3-thiophenol), 7.18 (d, *J* = 8.0 Hz, 1H, H^4-thiophenol), 5.54 (d, *J* = 2.4 Hz, 1H, H-1), 4.84 (dd, *J* = 6.3, 1.6 Hz, 1H, H-3), 4.80 (dd, *J* = 6.2, 2.5 Hz, 1H, H-2), 4.39 (ddd, *J* = 4.8, 3.4, 1.6 Hz, 1H, H-4), 3.85 (dd, *J* = 12.4, 3.4 Hz, 1H, H-5), 3.77 (dd, *J* = 12.3, 4.6 Hz, 1H, H-5), 2.43 (s, 3H, thiophenol-CH_3), 1.56 (s, 3H, isopropylidene-CH_3), 1.39 (s, 3H, isopropylidene-CH_3), 1.34 (d, *J* = 0.7 Hz, 9H, thiophenol-C$(CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.76 (C^5-thiophenol), 136.51 (C^1-thiophenol), 131.78 (C^2-thiophenol), 130.17 (C^3-thiophenol), 129.62 (C^6-thiophenol), 125.16 (C^4-thiophenol), 113.40 (quaternary-C), 92.29 (C-1), 87.78 (C-4), 86.19 (C-2), 81.89 (C-3), 63.37 (C-5), 34.49 (thiophenol-C$(CH_3)_3$), 31.30 (3C, thiophenol-C$(CH_3)_3$), 26.91 (isopropylidene-CH_3), 25.21 (isopropylidene-CH_3), 20.31(thiophenol-CH_3); HRMS (ESI^+) calcd. for Chemical Formula: $C_{19}H_{28}NaO_4S^+$ 375.1601, found 375.1611.

*4.2.2. (3aR,4S,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxole-4-carbaldehyde (**3b**)*

A solution of Dess-Martin periodinane (9 g, 22.1 mmol, 1.3 equiv.) in DCM (100 mL) was treated dropwise with another solution of compound **5** (6 g, 17.0 mmol, 1 equiv.) in DCM (50 mL). The mixture was stirred at RT for 4 h. The reaction was quenched by sat. aq. $NaHCO_3$ and sat. aq. $Na_2S_2O_3$, and extracted with DCM. The organic phase was washed with brine, concentrated, and purified with flash chromatography (on silica gel with 60–90 °C petroleum ether: EtOAc = 10:1–5:1) to give product **3b** (colorless oil, 4.6 g, 13.1 mmol, 77%). Compound **7**: R_f 0.30–0.80 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.44 min; $[\alpha]_D = -36$ (20 °C, c = 0.29, $CHCl_3$); ^{1}H NMR (600 MHz, Chloroform-d) δ 9.73 (s, 1H, −CHO), 7.62 (m, 1H, H^6-thiophenol), 7.21 (m, 1H, H^3-thiophenol), 7.13 (m, 1H, H^4-thiophenol), 5.87 (s, 1H, H-1), 5.21 (d, *J* = 6.0 Hz, 1H, H-3), 4.74 (d, *J* = 6.0 Hz, 1H, H-2), 4.48 (t, *J* = 0.9 Hz, 1H, H-4), 2.32 (s, 3H, thiophenol-CH_3), 1.53 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.33 (s, 9H, thiophenol-C$(CH_3)_3$); ^{13}C NMR (126 MHz, Chloroform-d) δ 200.51 (−CHO), 149.80 (C^5-thiophenol), 135.46 (C^1-thiophenol), 131.47 (C^2-thiophenol), 130.25 (C^3-thiophenol), 127.31 (C^6-thiophenol), 124.57 (C^4-thiophenol), 113.33 (quaternary-C), 91.23 (C-1), 90.06 (C-4), 85.00 (C-2), 81.76 (C-3), 34.60 (thiophenol-C$(CH_3)_3$), 31.34 (3C, thiophenol-C$(CH_3)_3$), 26.31 (isopropylidene-CH_3), 25.05 (isopropylidene-CH_3), 19.93 (thiophenol-CH_3); HRMS (ESI^+) calcd. for $C_{20}H_{30}NaO_5S^+$ 405.1706 (M+MeOH+Na^+), found 405.1723.

4.2.3. General procedure A

A solution of compound **3b** (50 mg, 0.14 mmol, 1 equiv.) in THF (3 mL) was cooled to −78 °C and treated with Grignard reagent (0.43 mmol, 3 equiv.). The mixture was stirred at this temperature for 2 h. The reaction was quenched by sat. aq. NH_4Cl, concentrated, and extracted TBME. The organic phase was washed with brine, concentrated, and purified with flash chromatography (on silica gel on silica gel with 60–90 °C petroleum ether: EtOAc = 20:1–10:1) to give products **6a,b** through **15**.

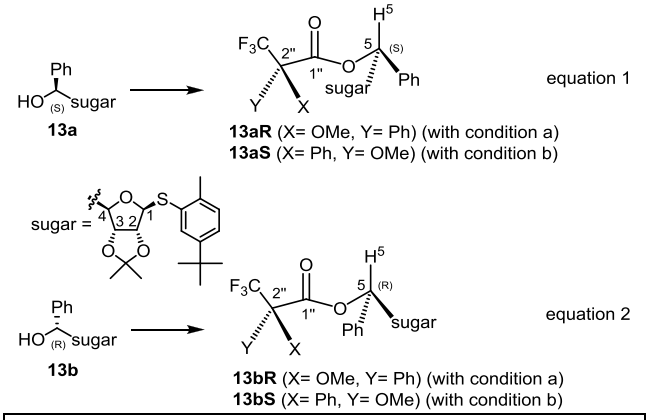
4.2.4. General procedure B

A solution of compound **3b** (200 mg, 0.57 mmol, 1 equiv.) in THF (10 mL) was cooled to 0 °C and treated with Grignard reagent (1.71 mmol, 3 equiv.). The mixture was stirred at this temperature for 5 h. The reaction was quenched by sat. aq. NH_4Cl, concentrated, and extracted TBME. The organic phase was washed with brine, concentrated, and purified with flash chromatography (on silica gel on silica gel with 60–90 °C petroleum ether: EtOAc = 20:1–10:1) to give products **6a,b** through **15**.

*4.2.5. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethan-1-ol (**6a**) and (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethan-1-ol (**6b**)*

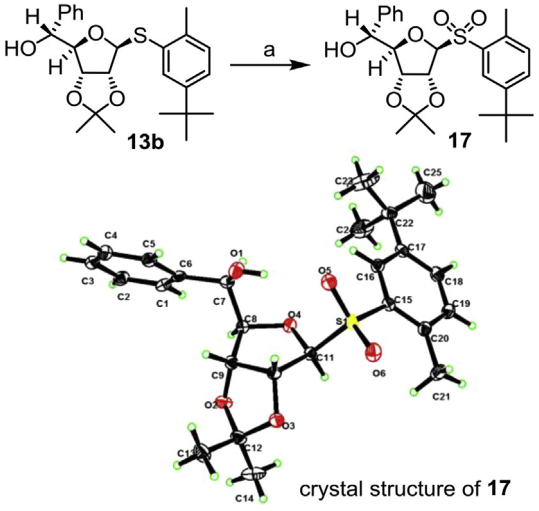
According to general procedure A, MeMgBr (3 M in Et_2O) yielded

Table 5
Determination of absolute stereochemistry on Mosher's acid derivatives **13aR**, **13aS**, **13bR**, and **13bS**.[a]



Selected NMR data (δ) of **13a** derivatives		
13aR (33% from **13a**)[b]	**13aS** (93% from **13a**)[b]	Δδ
H^3 = 4.34	H^3 = 4.50	-0.16
H^4 = 4.56	H^4 = 4.57	-0.01
H^5 = 6.15	H^5 = 6.15	0
CH_3O = 3.41	CH_3O = 3.37	+0.04
CF_3 = -71.72	CF_3 = -71.77	+0.05
Selected NMR data (δ) of **13b** derivatives		
13bR (86% from **13b**)[b]	**13bS** (66% from **13b**)[b]	Δδ
H^3 = 4.84	H^3 = 4.65	+0.19
H^4 = 4.47	H^4 = 4.53	-0.06
H^5 = 6.22	H^5 = 6.29	-0.07
CH_3O = 3.58	CH_3O = 3.46	+0.12
CF_3 = -71.55	CF_3 = -71.27	-0.28

[a] Reaction conditions: a) (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16a**), pyridine, MeCN; b) (*S*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16b**), pyridine, MeCN. [b] Chromatography separation yields.



Scheme 4. Oxidation of compound **13b** yielded compound **17**. Reaction conditions: a) *m*CPBA, DCM, RT, over night, 67%.

compound **6a** (colorless oil, 3 mg, 8.5 μmol, 6%) and compound **6b** (colorless oil, 45 mg, 0.12 mmol, 86%). Alternatively, according to general procedure B, MeMgBr (3 M in Et_2O) yielded compound **6a** (colorless oil, 22 mg, 0.06 mmol, 11%) and compound **6b** (colorless oil, 170 mg, 0.46 mmol, 82%). Compound **6a**: R_f 0.60 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.31 min; $[\alpha]_D$ = −30 (20 °C, c = 0.25, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.62 (m, 1H, H^6-thiophenol), 7.23 (m, 1H, H^3-thiophenol), 7.15 (m, 1H, H^4-thiophenol), 5.56 (d, *J* = 2.4 Hz, 1H, H-1), 4.79 (dd, *J* = 6.1, 2.4 Hz, 1H, H-2), 4.72 (dd, *J* = 6.2, 1.9 Hz, 1H, H-3), 4.07 (dd, *J* = 5.7, 1.9 Hz, 1H, H-4), 3.89 (m, 1H, H-5), 2.39 (s, 3H, thiophenol-CH_3), 1.53 (m, 3H, isopropylidene-CH_3), 1.36 (m, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-$C(CH_3)_3$), 1.26 (d, *J* = 6.4 Hz, 3H, −CH_3), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ149.83 (C^5-thiophenol), 136.17 (C^1-thiophenol), 132.02 (C^2-thiophenol), 130.21 (C^3-thiophenol), 128.96 (C^6-thiophenol), 124.96 (C^4-thiophenol), 113.46 (quaternary-C), 91.82 (C-1), 91.58 (C-4), 86.18 (C-2), 82.43 (C-3), 68.01 (C-5), 34.53 (thiophenol-$C(CH_3)_3$), 31.31 (3C, thiophenol-$C(CH_3)_3$), 26.92 (isopropylidene-CH_3), 25.24 (isopropylidene-CH_3), 20.22 (thiophenol-CH_3), 19.24 (−CH_3); HRMS (ESI^+) calcd. for $C_{20}H_{30}NaO_4S^+$ 389.1757, found 389.1766. Compound **6b**: R_f 0.42 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.26 min; $[\alpha]_D$ = −59 (20 °C, c = 0.69, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.58 (m, 1H, H^6-thiophenol), 7.23 (m, 1H, H^3-thiophenol), 7.15 (m, 1H, H^4-thiophenol), 5.45 (d, *J* = 3.0 Hz, 1H, H-1), 4.88 (dd, *J* = 6.4, 2.1 Hz, 1H, H-3), 4.71 (dd, *J* = 6.4, 3.0 Hz, 1H, H-2), 4.08 (dd, *J* = 3.3, 2.2 Hz, 1H, H-4), 4.04 (m, 1H, H-5), 2.40 (s, 3H, thiophenol −CH_3), 1.53 (s, 3H, isopropylidene-CH_3), 1.37 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol −$C(CH_3)_3$), 1.24 (d,

J = 6.4 Hz, 3H, $-CH_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.72 (C^5-thiophenol), 136.53 (C^1-thiophenol), 131.70 (C^2-thiophenol), 130.12 (C^3-thiophenol), 129.73 (C^6-thiophenol), 125.15 (C^4-thiophenol), 113.60(quaternary-C), 91.86 (C-1), 91.53 (C-4), 85.89 (C-2), 80.06 (C-3), 67.59 (C-5), 34.50 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.01 (isopropylidene-$\underline{C}H_3$), 25.24 (isopropylidene-CH_3), 20.33 (thiophenol-CH_3), 18.34 ($-CH_3$); HRMS (ESI^+) calcd. for $C_{20}H_{30}NaO_4S^+$ 389.1757, found 389.1759.

4.2.6. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)propan-1-ol (7)

a) According to general procedure A, EtMgBr (1 M in THF) yielded compound **7** (colorless oil, 35 mg, 92 μmol, 65%). Alternatively, according to general procedure B, EtMgBr (1 M in THF) yielded compound **7** (colorless oil, 148 mg, 0.39 mmol, 68%). Compound **7**: R_f 0.57 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.45 min; $[\alpha]_D = -47$ (20 °C, c = 0.34, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.58 (m, 1H, H^6-thiophenol), 7.25–7.20 (m, 1H, H^3-thiophenol), 7.15 (m, 1H, H^4-thiophenol), 5.44 (d, J = 3.0 Hz, 1H, H-1), 4.87 (dd, J = 6.3, 2.2 Hz, 1H, H-3), 4.71 (dd, J = 6.4, 3.0 Hz, 1H, H-2), 4.15 (dd, J = 3.4, 2.2 Hz, 1H, H-4), 3.76 (m, 1H, H-5), 2.39 (s, 3H thiophenol-CH_3), 1.58 (m, 1H, $-C\underline{H}_2CH_3$), 1.53 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C($CH_3)_3$), 1.01 (t, J = 7.4 Hz, 3H, $-CH_2C\underline{H}_3$), hydroxyl proton was not found; ^{13}C NMR (151 MHz, Chloroform-*d*) δ 149.71 (C^5-thiophenol), 136.49 (C^1-thiophenol), 131.81 (C^2-thiophenol), 130.12 (C^3-thiophenol), 129.63 (C^6-thiophenol), 125.12 (C^4-thiophenol), 113.54(quaternary-C), 91.84 (C-1), 90.33 (C-4), 85.96 (C-2), 80.37 (C-3), 73.03 (C-5), 34.51 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.02 (isopropylidene-$\underline{C}H_3$), 25.56 ($-\underline{C}H_2CH_3$), 25.23 (isopropylidene-CH_3), 20.36 (thiophenol-CH_3), 10.21 ($-CH_2\underline{C}H_3$); HRMS (ESI^+) calcd. for $C_{21}H_{32}NaO_4S^+$ 403.1914, found 403.1920.

b) Compound **9b** (30 mg, 72 μmol, 1 equiv.), prepared in section 4.2.8, was dissolved in MeOH (10 mL), treated with 10% Pd/C (100 mg), and subjected to hydrogenation condition at 1 atm and RT for 8 h. The reaction mixture was filtered, dried and purified with flash chromatography (on silica gel on silica gel with 60–90 °C petroleum ether: EtOAc = 10:1–5:1) to give product **7** (colorless oil, 24 mg, 63 μmol, 80%), which showed parallel proton NMR to that produced above.

4.2.7. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)-2-methylpropan-1-ol (8)

According to general procedure A, *i*-PrMgBr (1 M in THF) yielded compound **8** (colorless oil, 33 mg, 84 μmol, 59%). Alternatively, according to general procedure B, *i*-PrMgBr (1 M in THF) yielded compound **8** (colorless oil, 138 mg, 0.35 mmol, 61%). Compound **8**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.65 min; $[\alpha]_D = -31$ (20 °C, c = 0.35, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.58 (m, 1H, H^6-thiophenol), 7.22 (m, 1H, H^3-thiophenol), 7.14 (m, 1H, H^4-thiophenol), 5.44 (d, J = 3.0 Hz, 1H, H-1), 4.88 (dd, J = 6.4, 2.3 Hz, 1H, H-3), 4.70 (dd, J = 6.4, 3.0 Hz, 1H, H-2), 4.28 (dd, J = 4.0, 2.3 Hz, 1H, H-4), 3.57–3.49 (m, 1H, H-5), 2.39 (s, 3H, thiophenol-CH_3), 1.53 (s, 3H, isopropylidene-CH_3), 1.84 (m, 1H, $-C\underline{H}(CH_3)_2$), 1.36 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C($CH_3)_3$), 1.01 (d, J = 6.7 Hz, 3H, $-CH(C\underline{H}_3)_2$), 0.96 (d, J = 6.8 Hz, 3H, $-CH(C\underline{H}_3)_2$), hydroxyl proton was not found; ^{13}C NMR (151 MHz, Chloroform-*d*) δ 149.69 (C^5-thiophenol), 136.35 (C^1-thiophenol), 131.97 (C^2-thiophenol), 130.10(C^3-thiophenol), 129.41 (C^6-thiophenol), 124.99 (C^4-thiophenol), 113.57 (quaternary-C), 91.59 (C-1), 88.68 (C-4), 85.99 (C-2), 80.68 (C-3), 76.45 (C-5), 34.52 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 30.08 ($-\underline{C}H(CH_3)_2$), 27.05 (isopropylidene-CH_3), 25.26 (isopropylidene-CH_3), 20.33 (thiophenol-CH_3), 19.21 ($-CH(\underline{C}H_3)_2$), 18.09 ($-CH(\underline{C}H_3)_2$); HRMS (ESI^+) calcd. for $C_{22}H_{34}NaO_4S^+$ 417.2070, found 417.2079.

4.2.8. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)prop-2-en-1-ol (9a) and (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)prop-2-en-1-ol (9b)

According to general procedure A, vinylmagnesium bromide (1 M in THF) yielded compound **9a** (colorless oil, 4 mg, 9.7 μmol, 6.8%) and compound **9b** (colorless oil, 37 mg, 98 μmol, 69%). Alternatively, according to general procedure B, vinylmagnesium bromide (1 M in THF) yielded compound **9a** (colorless oil, 24 mg, 63 μmol, 11%) and compound **9b** (colorless oil, 130 mg, 0.34 mmol, 60%). Compound **9a**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.41 min; $[\alpha]_D = -18$ (20 °C, c = 0.45, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.60 (m, 1H, H^6-thiophenol), 7.23 (m, 1H, H^4-thiophenol), 7.15 (m, 1H, H^3-thiophenol), 5.87 (m, 1H, $-C\underline{H}=CH_2$); 5.55 (d, J = 1.9 Hz, 1H, H-1), 5.42 (m, 1H, $-CH=C\underline{H}_2$), 5.29 (m, 1H, $-CH=C\underline{H}_2$), 4.85–4.77 (m, 2H, H-2, H-3), 4.27 (m, 1H, H-5), 4.22 (dd, J = 5.9, 1.4 Hz, 1H, H-4), 2.40 (s, 3H, thiophenol-CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.30 (s, 9H, thiophenol-C($CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.83 (C^5-thiophenol), 136.39 (C^1-thiophenol), 136.33 ($-\underline{C}H=CH_2$), 131.85 (C^2-thiophenol), 130.19 (C^3-thiophenol), 129.40 (C^6-thiophenol), 125.10 (C^4-thiophenol), 117.87 ($-CH=\underline{C}H_2$), 113.51 (quaternary-C), 92.19 (C-1), 90.13 (C-4), 86.13 (C-2), 82.07 (C-3), 73.13 (C-5), 34.53 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.89 (isopropylidene-$\underline{C}H_3$), 25.26 (isopropylidene-CH_3), 20.28 (thiophenol-CH_3); HRMS (ESI^+) calcd. for $C_{21}H_{30}NaO_4S^+$ 401.1757, found 401.1768. Compound **9b**: R_f 0.53 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.40 min; $[\alpha]_D = -47$ (20 °C, c = 0.26, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.59 (m, 1H, H^6-thiophenol), 7.23 (m, 1H, H^4-thiophenol), 7.16 (m, 1H, H^3-thiophenol), 5.89 (ddd, J = 17.2, 10.7, 4.6 Hz, 1H, $-C\underline{H}=CH_2$), 5.46 (m, 2H, $-CH=C\underline{H}_2$, H-1), 5.30 (m, 1H, $-CH=C\underline{H}_2$), 4.85 (dd, J = 6.3, 2.0 Hz, 1H, H-2), 4.73 (dd, J = 6.3, 2.9 Hz, 1H, H-3), 4.45 (m, 1H, H-5), 4.25 (m, 1H, H-4), 2.40 (s, 3H, thiophenol-CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.35 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C($CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.77 (C^5-thiophenol), 136.53 (C^1-thiophenol), 135.03 ($-\underline{C}H=CH_2$), 131.71 (C^2-thiophenol), 130.15 (C^3-thiophenol), 129.74 (C^6-thiophenol), 125.21 (C^4-thiophenol), 117.08 ($-CH=\underline{C}H_2$), 113.49 (quaternary-C), 92.57 (C-1), 90.36 (C-4), 85.92 (C-2), 80.17 (C-3), 72.12 (C-5), 34.51 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.00 (isopropylidene-$\underline{C}H_3$), 25.26 (isopropylidene-CH_3), 20.36 (thiophenol-CH_3); HRMS (ESI^+) calcd. for $C_{21}H_{30}NaO_4S^+$ 401.1757, found 401.1762.

4.2.9. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)-2-methylprop-2-en-1-ol (10a) and (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)-2-methylprop-2-en-1-ol (10b)

According to general procedure A, isopropenylmagnesium bromide (1 M in THF) yielded compound **10a** (colorless oil, 11 mg, 28 μmol, 19%) and compound **10b** (colorless oil, 32 mg, 82 μmol, 57%). Alternatively, according to general procedure B, vinylmagnesium bromide (1 M in THF) yielded compound **10a** (colorless oil, 69 mg, 0.18 mmol, 31%) and compound **10b** (colorless oil,

105 mg, 0.27 mmol, 47%). Compound **10a**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.61 min; $[\alpha]_D = -62$ (20 °C, c = 0.35, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.60 (m, 1H, H^6-thiophenol), 7.21 (m, 1H, H^4-thiophenol), 7.14 (m, 1H, H^3-thiophenol), 5.54 (d, *J* = 2.0 Hz, 1H, H-1), 5.08 (m, 1H, =CH_2), 5.01 (m, 1H, =CH_2), 4.80 (m, 2H, H-2, H-3), 4.39 (dd, *J* = 5.8, 1.6 Hz, 1H, H-4), 4.19 (d, *J* = 5.7 Hz, 1H, H-5), 2.39 (s, 3H, thiophenol-CH_3), 1.80 (s, 3H, −CH_3), 1.53 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.30 (s, 9H, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.78(C^5-thiophenol), 143.49 (-C(=CH_2)), 136.28 (C^1-thiophenol), 132.01 (C^2-thiophenol), 130.11 (C^3-thiophenol), 129.33 (C^6-thiophenol), 124.99 (C^4-thiophenol), 113.71 (-C(=CH_2)), 113.43 (quaternary-C), 92.36 (C-1), 88.76 (C-4), 86.23 (C-2), 82.56 (C-3), 75.52 (C-5), 34.52 (thiophenol-C(CH_3)$_3$), 31.29 (3C, thiophenol-C(CH_3)$_3$), 26.91 (isopropylidene-CH_3), 25.24 (isopropylidene-CH_3), 20.27 (thiophenol-CH_3), 18.63 (-C(CH_3)=CH_2); HRMS (ESI$^+$) calcd. for $C_{22}H_{32}NaO_4S^+$ 415.1914, found 415.1923. Compound **10b**: R_f 0.53 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.58 min; $[\alpha]_D = -92$ (20 °C, c = 0.44, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.59 (m, 1H, H^6-thiophenol), 7.23 (m, 1H, H^4-thiophenol), 7.15 (m, 1H, H^3-thiophenol), 5.48 (d, *J* = 2.9 Hz, 1H, H-1), 5.21 (m, 1H, =CH_2), 5.03 (m, 1H, =CH_2), 4.84 (dd, *J* = 6.3, 2.1 Hz, 1H, H-3), 4.73 (dd, *J* = 6.3, 2.9 Hz, 1H, H-2), 4.37 (dd, *J* = 3.4, 2.2 Hz, 1H, H-4), 4.30 (d, *J* = 3.4 Hz, 1H, H-5), 2.40 (s, 3H, thiophenol-CH_3), 1.79 (s, 3H, −CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.35 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.74 (C^5-thiophenol), 142.11 (-C(=CH_2)), 136.45 (C^1-thiophenol), 131.88 (C^2-thiophenol), 130.11 (C^3-thiophenol), 129.67 (C^6-thiophenol), 125.13 (C^4-thiophenol), 113.44 (quaternary-C), 112.86 (-C(=CH_2)), 92.57 (C-1), 88.91 (C-4), 85.98 (C-2), 80.21 (C-3), 74.39 (C-5), 34.51 (thiophenol-C(CH_3)$_3$), 31.31 (3C, thiophenol-C(CH_3)$_3$), 27.05 (isopropylidene-CH_3), 25.29 (isopropylidene-CH_3), 20.36 (thiophenol-CH_3), 19.81 (-C(CH_3)=CH_2); HRMS (ESI$^+$) calcd. for $C_{22}H_{32}NaO_4S^+$ 415.1914, found 415.1920.

*4.2.10. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)but-3-en-1-ol (**12a**) and (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)but-3-en-1-ol (**12b**)*

According to general procedure A, allylmagnesium chloride (1 M in THF) yielded compound **12a** (colorless oil, 6 mg, 15 μmol, 10%) and compound **12b** (colorless oil, 29 mg, 74 μmol, 52%). Alternatively, according to general procedure B, allylmagnesium chloride (1 M in THF) yielded compound **12a** (colorless oil, 30 mg, 76 μmol, 13%) and compound **12b** (colorless oil, 157 mg, 0.40 mmol, 70%). Compound **12a**: R_f 0.65 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.62 min; $[\alpha]_D = -46$ (20 °C, c = 0.22, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.63 (m, 1H, H^6-thiophenol), 7.22 (m, 1H, H^4-thiophenol), 7.15 (m, 1H, H^3-thiophenol), 5.85 (m, 1H, −CH_2CH=CH_2), 5.53 (d, *J* = 2.4 Hz, 1H, H-1), 5.12 (m, 2H, −CH_2CH=CH_2), 4.79 (m, 2H, H-2, H-3), 4.24 (dd, *J* = 4.2, 1.7 Hz, 1H, H-4), 3.73 (m, 1H, H-5), 2.43–2.31 (m, 5H, −CH_2CH=CH_2, thiophenol-CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.81 (C^5-thiophenol), 136.03 (C^1-thiophenol), 133.98 (−CH_2CH=CH_2), 132.12 (C^2-thiophenol), 130.16 (C^3-thiophenol), 128.77 (C^6-thiophenol), 124.90 (C^4-thiophenol), 117.85 (−CH_2CH=CH_2), 113.44 (quaternary-C), 92.23 (C-1), 89.30 (C-4), 86.08 (C-2), 82.62 (C-3), 71.56 (C-5), 38.40 (−CH_2CH=CH_2), 34.54 (thiophenol-C(CH_3)$_3$), 31.32 (3C, thiophenol-C(CH_3)$_3$), 26.96 (isopropylidene-CH_3), 25.21 (isopropylidene-CH_3), 20.23 (thiophenol-CH_3); HRMS (ESI$^+$) calcd. for $C_{22}H_{32}NaO_4S^+$ 415.1914, found 415.1915. Compound **12b**: R_f 0.71 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.52 min; $[\alpha]_D = -44$ (20 °C, c = 0.34, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.58 (m, 1H, H^6-thiophenol), 7.22 (m, 1H, H^4-thiophenol), 7.13 (m, 1H, H^3-thiophenol), 5.84 (m, 1H, −CH_2CH=CH_2), 5.49 (d, *J* = 2.6 Hz, 1H, H-1), 5.15 (m, 2H, −CH_2CH=CH_2), 4.92 (dd, *J* = 6.3, 2.2 Hz, 1H, H-3), 4.74 (dd, *J* = 6.3, 2.7 Hz, 1H, H-2), 4.12 (dd, *J* = 4.7, 2.2 Hz, 1H, H-4), 3.92 (m, 1H, H-5), 2.32 (m, 5H, −CH_2CH=CH_2, thiophenol-CH_3), 1.53 (s, 3H, isopropylidene-CH_3), 1.36 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.71 (C^5-thiophenol), 136.23 (C^1-thiophenol), 133.82 (−CH_2CH=CH_2), 131.99 (C^2-thiophenol), 130.09 (C^3-thiophenol), 129.23 (C^6-thiophenol), 124.93 (C^4-thiophenol), 118.41 (−CH_2CH=CH_2), 113.55 (quaternary-C), 91.80 (C-1), 89.86 (C-4), 86.02 (C-2), 80.79 (C-3), 70.76 (C-5), 37.33 (−CH_2CH=CH_2), 34.51 (thiophenol-C(CH_3)$_3$), 31.31 (3C, thiophenol-C(CH_3)$_3$), 26.97 (isopropylidene-CH_3), 25.24 (isopropylidene-CH_3), 20.29 (thiophenol-CH_3); HRMS (ESI$^+$) calcd. for $C_{22}H_{32}NaO_4S^+$ 415.1914, found 415.1919.

*4.2.11. (S)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl)methanol (**13a**) and (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl)methanol (**13b**)*

According to general procedure A, phenylmagnesium bromide (1 M in THF) yielded compound **13a** (colorless oil, 11 mg, 25 μmol, 17%) and compound **13b** (colorless oil, 41 mg, 96 μmol, 67%). Alternatively, according to general procedure B, phenylmagnesium bromide (1 M in THF) yielded compound **13a** (colorless oil, 61 mg, 0.14 mmol, 25%) and compound **13b** (colorless oil, 133 mg, 0.31 mmol, 54%). Compound **13a**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.65 min; $[\alpha]_D = -46$ (20 °C, c = 0.45, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.58 (m, 1H, H^6-thiophenol), 7.35 (m, 5H, Ph), 7.22 (m, 1H, H^4-thiophenol), 7.15 (m, 1H, H^3-thiophenol), 5.62 (d, *J* = 2.2 Hz, 1H, H-1), 4.87 (m, 2H, H-2, H-5), 4.78 (dd, *J* = 6.1, 1.8 Hz, 1H, H-3), 4.46 (dd, *J* = 6.7, 1.8 Hz, 1H, H-4), 2.40 (s, 3H, thiophenol-CH_3), 1.50 (s, 3H, isopropylidene-CH_3), 1.31 (s, 3H, isopropylidene-CH_3), 1.27 (s, 9H, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.93 (C^5-thiophenol), 139.58 (1C, Ph), 136.07 (C^1-thiophenol), 132.16 (C^2-thiophenol), 130.22 (C^3-thiophenol), 128.71 (C^6-thiophenol), 128.63 (2C, Ph), 128.19 (1C, Ph), 127.05 (2C, Ph), 124.92 (C^4-thiophenol), 113.44 (quaternary-C), 92.19 (C-1), 91.41 (C-4), 86.27 (C-2), 82.01 (C-3), 74.20 (C-5), 34.51 (thiophenol-C(CH_3)$_3$), 31.31 (3C, thiophenol-C(CH_3)$_3$), 26.85 (isopropylidene-CH_3), 25.24 (isopropylidene-CH_3), 20.21 (thiophenol-CH_3); HRMS (ESI$^+$) calcd. for $C_{25}H_{32}NaO_4S^+$ 451.1914, found 451.1921. Compound **13b**: R_f 0.58 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.64 min; $[\alpha]_D = -35$ (20 °C, c = 0.47, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.57 (m, 1H, H^6-thiophenol), 7.35 (m, 5H, Ph), 7.24 (m, 1H, H^4-thiophenol), 7.16 (m, 1H, H^3-thiophenol), 5.52 (d, *J* = 2.8 Hz, 1H, H-1), 5.02 (m, 1H, H-5), 4.88 (dd, *J* = 6.2, 1.6 Hz, 1H, H-3), 4.79 (dd, *J* = 6.2, 2.9 Hz, 1H, H-2), 4.50 (dd, *J* = 4.0, 1.6 Hz, 1H, H-4), 2.42 (s, 3H, thiophenol-CH_3), 1.47 (s, 3H, isopropylidene-CH_3), 1.29 (m, 12H, isopropylidene-CH_3, thiophenol-C(CH_3)$_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.80 (C^5-thiophenol), 139.04 (1C, Ph), 136.31 (C^1-thiophenol), 131.91 (C^2-thiophenol), 130.13 (C^3-thiophenol), 129.46 (C^6-thiophenol), 128.55 (2C, Ph), 127.72 (1C, Ph), 126.12 (2C, Ph), 125.11 (C^4-thiophenol), 113.30 (quaternary-C), 92.90 (C-1), 91.92 (C-4), 86.05 (C-2), 80.36 (C-3), 73.58 (C-5), 34.50 (thiophenol-C(CH_3)$_3$), 31.31 (3C, thiophenol-C(CH_3)$_3$), 26.98 (isopropylidene-CH_3), 25.25 (isopropylidene-CH_3), 20.36 (thiophenol-CH_3); HRMS (ESI$^+$) calcd. for $C_{25}H_{32}NaO_4S^+$ 451.1914, found 451.1920.

4.2.12. (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(4-fluorophenyl)methanol (**14a**) and (S)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl)thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3] dioxol-4-yl)(4-fluorophenyl)methanol (**14b**)

According to general procedure A, 4-fluorophenylmagnesium bromide (1 M in THF) yielded compound **14a** (colorless oil, 39 mg, 87 μmol, 61%) and compound **14b** (colorless oil, 18 mg, 40 μmol, 28%). Alternatively, according to general procedure B, 4-fluorophenylmagnesium bromide (1 M in THF) yielded compound **14a** (colorless oil, 173 mg, 0.39 mmol, 68%) and compound **14b** (colorless oil, 49 mg, 0.11 mmol, 19%). Compound **14a**: R_f 0.52 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.64 min; $[\alpha]_D = -52$ (20 °C, c = 0.34, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.56 (m, 1H, H^6-thiophenol), 7.37 (m, 2H, H-fluobenzene), 7.23 (m, 1H, H^4-thiophenol), 7.15 (m, 1H, H^3-thiophenol), 7.03 (m, 2H, H-fluobenzene), 5.63 (d, *J* = 2.1 Hz, 1H, H-1), 4.86 (m, 2H, H-2, H-5), 4.75 (dd, *J* = 6.2, 1.8 Hz, 1H, H-3), 4.41 (dd, *J* = 6.7, 1.9 Hz, 1H, H-4), 2.39 (s, 3H, thiophenol-CH_3), 1.50 (s, 3H, isopropylidene-CH_3), 1.32 (s, 3H, isopropylidene-CH_3), 1.27 (s, 9H, thiophenol-C$(CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 162.55 (d, *J* = 246.5 Hz, C-fluobenzene), 149.96 (C^5-thiophenol), 136.04 (C^1-thiophenol), 135.42 (C-fluobenzene), 131.99 (C^2-thiophenol), 130.27 (C^3-thiophenol), 128.78 (2C, d, *J* = 8.1 Hz, C-fluobenzene), 128.61 (C^6-thiophenol), 124.96 (C^4-thiophenol), 115.54 (2C, d, *J* = 21.6 Hz, C-fluobenzene), 113.54 (quaternary-C), 92.03 (C-1), 91.38 (C-4), 86.23 (C-2), 81.91 (C-3), 73.58 (C-5), 34.51 (thiophenol-C$(CH_3)_3$), 31.31 (3C, thiophenol-C(C$H_3)_3$), 26.83 (isopropylidene-CH_3), 25.21 (isopropylidene-CH_3), 20.18 (thiophenol-CH_3); ^{19}F NMR (471 MHz, Chloroform-*d*) δ −114.11 (m), HRMS (ESI^+) calcd. for $C_{25}H_{31}FNaO_4S^+$ 469.1819, found 469.1827. Compound **14b**: R_f 0.46 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.66 min; $[\alpha]_D = -42$ (20 °C, c = 0.29, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.54 (m, 1H, H^6-thiophenol), 7.42–7.34 (m, 2H, H-fluobenzene), 7.24 (m, 1H, H^4-thiophenol), 7.16 (m, 1H, H^3-thiophenol), 7.03 (m, 2H, H-fluobenzene), 5.53 (d, *J* = 2.7 Hz, 1H, H-1), 4.99 (d, *J* = 4.1 Hz, 1H, H-5), 4.86 (dt, *J* = 6.2, 1.4 Hz, 1H, H-3), 4.79 (dd, *J* = 6.3, 2.7 Hz, 1H, H-2), 4.44 (dd, *J* = 4.1, 1.8 Hz, 1H, H-4), 2.41 (s, 3H, thiophenol-CH_3), 1.48 (s, 3H, isopropylidene-CH_3), 1.30 (s, 3H, isopropylidene-CH_3), 1.28 (s, 9H, thiophenol-C$(CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 162.24 (d, *J* = 245.7 Hz, C-fluobenzene), 149.83 (C^5-thiophenol), 136.16 (C^1-thiophenol), 134.90 (C-fluobenzene), 131.88 (C^2-thiophenol), 130.14 (C^3-thiophenol), 129.22 (C^6-thiophenol), 127.81 (2C, d, *J* = 8.1 Hz, C-fluobenzene), 125.07 (C^4-thiophenol), 115.53 (2C, d, *J* = 21.4 Hz, C-fluobenzene), 113.43 (quaternary-C), 92.67 (C-1), 91.81 (C-4), 86.02 (C-2), 80.36 (C-3), 72.99 (C-5), 34.50 (thiophenol-C$(CH_3)_3$), 31.29 (3C, thiophenol-C(C$H_3)_3$), 26.95 (isopropylidene-CH_3), 25.23 (isopropylidene-CH_3), 20.33 (thiophenol-CH_3); ^{19}F NMR (471 MHz, Chloroform-*d*) δ −114.76 (m), HRMS (ESI^+) calcd. for $C_{25}H_{31}FNaO_4S^+$ 469.1819, found 469.1823.

4.2.13. (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(o-tolyl) methanol (**15**)

According to general procedure A, 2-methylphenylmagnesium bromide (0.9 M in THF) yielded compound **15** (colorless oil, 46 mg, 0.10 mmol, 73%). Alternatively, according to general procedure B, 2-methylphenylmagnesium bromide (0.9 M in THF) yielded compound **15** (colorless oil, 199 mg, 0.45 mmol, 79%). Compound **15**: R_f 0.67 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 4.78 min; $[\alpha]_D = -53$ (20 °C, c = 0.56, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.60 (m, 2H, H^6-thiophenol, H-toluene), 7.20 (m, 5H, 2H-thiophenol, 3H-toluene), 5.49 (d, *J* = 3.0 Hz, 1H, H-1), 5.18 (d, *J* = 2.9 Hz, 1H, H-5), 4.99 (dd, *J* = 6.2, 1.6 Hz, 1H, H-3), 4.81 (dd, *J* = 6.2, 3.0 Hz, 1H, H-2), 4.45 (dd, *J* = 2.9, 1.6 Hz, 1H, H-4), 2.43 (s, 3H, thiophenol-CH_3), 2.33 (s, 3H, toluene-CH_3), 1.47 (s, 3H, isopropylidene-CH_3), 1.30 (m, 12H, isopropylidene-CH_3, thiophenol-C$(CH_3)_3$), hydroxyl proton was not found; ^{13}C NMR (126 MHz, Chloroform-*d*) δ 149.78 (C^5-thiophenol), 136.91 (toluene), 136.63 (C^1-thiophenol), 134.93 (toluene), 131.67 (C^2-thiophenol), 130.57 (toluene), 130.18 (C^3-thiophenol), 130.02 (toluene), 127.72 (C^6-thiophenol), 126.34 (toluene), 125.49 (toluene), 125.30 (C^4-thiophenol), 113.22 (quaternary-C), 92.99 (C-1), 90.01 (C-4), 86.07 (C-2), 80.12 (C-3), 71.09 (C-5), 34.50 (thiophenol-C$(CH_3)_3$), 31.31 (3C, thiophenol-C(C$H_3)_3$), 27.00 (isopropylidene-CH_3), 25.23 (isopropylidene-CH_3), 20.38 (thiophenol-CH_3), 19.18 (toluene-CH_3); HRMS (ESI^+) calcd. for $C_{26}H_{34}NaO_4S^+$ 465.2070, found 465.2081.

4.2.14. (R)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16a**)

The method was adapted from literature.[7] A solution of DMF (93.6 mg, 1.28 mmol, 3 equiv.) and (*R*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoic acid (100 mg, 0.43 mmol, 1 equiv.) in MeCN (5 mL) was cooled to 0 °C and treated with oxalyl chloride (366.2 mg, 2.56 mmol, 6 equiv.). The mixture was stirred at this temperature for 2 h, evaporated to dryness at 45 °C, co-evaporated with toluene at 45 °C to remove the excessive oxalyl chloride, and yield compound **16a** (brown oil, 98 mg, 0.38 mmol, 90%), which was used without further purification.

4.2.15. (S)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoyl chloride (**16b**)

The method was adapted from literature.[7] A solution of DMF (93.6 mg, 1.28 mmol, 3 equiv.) and (*S*)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoic acid (100 mg, 0.43 mmol, 1 equiv.) in MeCN (5 mL) was cooled to 0 °C and treated with oxalyl chloride (366.2 mg, 2.56 mmol, 6 equiv.). The mixture was stirred at this temperature for 2 h, evaporated to dryness at 45 °C, co-evaporated with toluene at 45 °C to remove the excessive oxalyl chloride, and yield compound **16b** (brown oil, 101 mg, 0.40 mmol, 93%), which was used without further purification.

4.2.16. General procedure C

The method was adapted from literature.[7] A solution of compound **16a** or **16b** (10 mg, 40 μmol, 1.5 equiv.) in MeCN (0.5 mL) was treated dropwise with another solution of compound **6a/b, 9a/b, 12a/b, 13a/b** (26 μmol, 1 equiv.) and pyridine (5 mg, 63 μmol, 2.4 equiv.) in MeCN (0.5 mL). The mixture was stirred at RT for 2 h and subjected directly to preparative TLC (on silica gel with 60–90 °C petroleum ether: EtOAc = 10:1) to give Mosher's acid derivatives in Tables 2–5.

4.2.17. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**6aR**)

According to general procedure *C*, compound **6a** (10 mg, 27 μmol, 1 equiv.) yielded compound **6aR** (colorless oil, 6 mg, 10 μmol, 38%). Compound **6aR**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.32 min; $[\alpha]_D = -11$ (20 °C, c = 0.34, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.63–7.57 (m, 2H, Ar), 7.54 (m, H^6-thiophenol), 7.42–7.34 (m, 3H, Ar), 7.18 (m, 1H, H^3-thiophenol), 7.10 (m, 1H, H^4-thiophenol), 5.24 (d, *J* = 3.8 Hz, 1H, H-1), 5.19 (m, 1H, H-5), 4.17 (dd, *J* = 4.6, 2.1 Hz, 1H, H-4), 4.13 (dd, *J* = 6.1, 2.2 Hz, 1H, H-3), 4.07 (dd, *J* = 6.1, 3.8 Hz, 1H, H-2), 3.59 (s, 3H, −OCH_3), 2.37 (s, 3H, thiophenol-CH_3), 1.45 (m, 6H, isopropylidene-CH_3, −CH_3), 1.28 (s, 9H, thiophenol-C$(CH_3)_3$), 1.17 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.98 (C=O), 149.61 (C^5-thiophenol), 135.96 (C^1-thiophenol), 133.63 (C^2-

thiophenol), 132.66 (Ph-MTPA), 129.85 (C^3-thiophenol), 129.58 (Ph-MTPA), 128.63 (C^6-thiophenol), 128.40 (2C, Ph-MTPA), 127.11 (2C, Ph-MTPA), 124.41 (C^4-thiophenol), 113.82 (quaternary-C), 92.68 (C-1), 86.63 (C-4), 85.30 (C-2), 81.67 (C-3), 73.42 (C-5), 55.93 ($-OCH_3$), 34.50 (thiophenol-$\underline{C}(CH_3)_3$), 31.31 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.14 (isopropylidene-CH_3), 25.12 (isopropylidene-CH_3), 20.29 (thiophenol-CH_3), 15.93 ($-CH_3$), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.92; HRMS (ESI^+) calcd. for $C_{30}H_{37}F_3NaO_6S^+$ 605.2155, found 605.2161.

4.2.18. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**6aS**)

According to general procedure *C*, compound **6a** (10 mg, 27 μmol, 1 equiv.) yielded compound **6aS** (colorless oil, 14 mg, 24 μmol, 88%). Compound **6aS**: R_f 0.67 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.32 min; $[\alpha]_D = -19$ (20 °C, c = 0.39, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.60–7.55 (m, 2H, Ar), 7.53 (m, 1H, H^6-thiophenol), 7.35 (m, 3H, Ar), 7.22 (m, 1H, H^3-thiophenol), 7.14 (m, 1H, H^4-thiophenol), 5.44 (d, *J* = 3.4 Hz, 1H, H-1), 5.30 (m, 1H, H-5), 4.67 (dd, *J* = 6.4, 3.4 Hz, 1H, H-2), 4.51 (dd, *J* = 6.4, 3.5 Hz, 1H, H-3), 4.13 (dd, *J* = 7.7, 3.5 Hz, 1H, H-4), 3.46 (s, 3H, $-OCH_3$), 2.38 (s, 3H, thiophenol-CH_3), 1.55 (s, 3H, isopropylidene-CH_3), 1.35 (m, 6H, isopropylidene-CH_3, $-CH_3$), 1.30 (s, 9H, thiophenol-C($CH_3)_3$); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.90 (C=O), 149.64 (C^5-thiophenol), 136.53 (C^1-thiophenol), 132.20 (C^2-thiophenol), 132.16 (Ph-MTPA), 130.10 (C^3-thiophenol), 129.51 (Ph-MTPA), 128.75 (C^6-thiophenol), 128.41 (2C, Ph-MTPA), 127.38 (2C, Ph-MTPA), 124.78 (C^4-thiophenol), 114.59 (quaternary-C), 90.67 (C-1), 86.97 (C-4), 85.34 (C-2), 81.34 (C-3), 73.16 (C-5), 55.51 ($-OCH_3$), 34.49 (thiophenol-$\underline{C}(CH_3)_3$), 31.29 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.20 (isopropylidene-CH_3), 25.40 (isopropylidene-CH_3), 20.29 (thiophenol-CH_3), 15.60 ($-\underline{C}H_3$), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.40; HRMS (ESI^+) calcd. for $C_{30}H_{37}F_3NaO_6S^+$ 605.2155, found 605.2147.

4.2.19. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**6bR**)

According to general procedure *C*, compound **6b** (10 mg, 27 μmol, 1 equiv.) yielded compound **6bR** (colorless oil, 8 mg, 14 μmol, 50%). Compound **6bR**: R_f 0.73 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.45 min; $[\alpha]_D = -28$ (20 °C, c = 0.19, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.61 (m, 3H, Ar), 7.44 (m, 3H, Ar), 7.23 (m, 1H, H^3-thiophenol), 7.16 (m, 1H, H^4-thiophenol), 5.47 (m, 1H, H-5), 5.42 (d, *J* = 3.0 Hz, 1H, H-1), 4.74–4.65 (m, 2H, H-2, H-3), 4.08 (dd, *J* = 7.1, 2.3 Hz, 1H, H-4), 3.62 (s, 3H, $-OCH_3$), 2.35 (s, 3H, thiophenol-CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.34 (s, 3H, isopropylidene-CH_3), 1.32 (s, 9H, thiophenol-C($CH_3)_3$), 1.29 (d, *J* = 8.1 Hz, 3H, $-CH_3$); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.88 (C=O), 149.71 (C^5-thiophenol), 135.88 (C^1-thiophenol), 132.63 (Ph-MTPA), 132.02 (C^2-thiophenol), 129.99 (C^3-thiophenol), 129.66 (Ph-MTPA), 128.53 (2C, Ph-MTPA), 128.51 (C^6-thiophenol), 127.44 (2C, Ph-MTPA), 124.59 (C^4-thiophenol), 114.42 (quaternary-C), 90.87 (C-1), 87.31 (C-4), 85.30 (C-2), 81.24 (C-3), 72.28 (C-5), 55.61 ($-OCH_3$), 34.54 (thiophenol-$\underline{C}(CH_3)_3$), 31.32 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.01 (isopropylidene-CH_3), 25.22 (isopropylidene-CH_3), 20.21 (thiophenol-CH_3), 16.65 ($-\underline{C}H_3$), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.43; HRMS (ESI^+) calcd. for $C_{30}H_{37}F_3NaO_6S^+$ 605.2155, found 605.2149.

4.2.20. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**6bS**)

According to general procedure *C*, compound **6b** (10 mg, 27 μmol, 1 equiv.) yielded compound **6bS** (colorless oil, 13 mg, 22 μmol, 82%). Compound **6bS**: R_f 0.70 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.39 min; $[\alpha]_D = -61$ (20 °C, c = 0.31, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.57 (m, 3H, Ar), 7.44–7.39 (m, 3H, Ar), 7.20 (m, 1H, H^3-thiophenol), 7.12 (m, 1H, H^4-thiophenol), 5.47–5.39 (m, 2H, H-1, H-5), 4.65 (dd, *J* = 6.4, 2.9 Hz, 1H, H-2), 4.50 (dd, *J* = 6.4, 2.2 Hz, 1H, H-3), 4.03 (dd, *J* = 8.2, 2.2 Hz, 1H, H-4), 3.57 (s, 3H, $-OCH_3$), 2.36 (s, 3H, thiophenol-CH_3), 1.46 (s, 3H, isopropylidene-CH_3), 1.37 (d, *J* = 6.3 Hz, 3H, $-CH_3$), 1.30 (s, 9H, thiophenol-C($CH_3)_3$), 1.26 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.81 (C=O), 149.67 (C^5-thiophenol), 135.77 (C^1-thiophenol), 132.67 (Ph-MTPA), 132.18 (C^2-thiophenol), 129.99 (C^3-thiophenol), 129.64 (Ph-MTPA), 128.49 (2C, Ph-MTPA), 128.32 (C^6-thiophenol), 127.34 (2C, Ph-MTPA), 124.48 (C^4-thiophenol), 113.92 (quaternary-C), 91.19 (C-1), 87.70 (C-4), 85.44 (C-2), 81.47 (C-3), 72.06 (C-5), 55.54 ($-OCH_3$), 34.54 (thiophenol-$\underline{C}(CH_3)_3$), 31.33 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.80 (isopropylidene-CH_3), 25.02 (isopropylidene-CH_3), 20.17 (thiophenol-CH_3), 17.15 ($-\underline{C}H_3$), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.50; HRMS (ESI^+) calcd. for $C_{30}H_{37}F_3NaO_6S^+$ 605.2155, found 605.2160.

4.2.21. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)allyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**9aR**)

According to general procedure *C*, compound **9a** (10 mg, 27 μmol, 1 equiv.) yielded compound **9aR** (colorless oil, 5 mg, 8.4 μmol, 32%). Compound **9aR**: R_f 0.69 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.49 min; $[\alpha]_D = -13$ (20 °C, c = 0.23, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.59 (m, 3H, Ar, H^6-thiophenol), 7.46–7.37 (m, 3H, Ar), 7.20 (m, 1H, H^3-thiophenol), 7.13 (m, 1H, H^4-thiophenol), 5.84–5.72 (m, 2H, H-5, $-\underline{C}H{=}CH_2$), 5.34 (d, *J* = 3.8 Hz, 1H, H-1), 5.28 (m, 2H, $-CH{=}\underline{C}H_2$), 4.69 (dd, *J* = 6.6, 2.8 Hz, 1H, H-3), 4.63 (dd, *J* = 6.6, 3.8 Hz, 1H, H-2), 4.19 (dd, *J* = 6.1, 2.8 Hz, 1H, H-4), 3.61 (s, 3H, $-OCH_3$), 2.37 (s, 3H, thiophenol-CH_3), 1.51 (s, 3H, isopropylidene-CH_3), 1.32 (s, 3H, isopropylidene-CH_3), 1.29 (s, 9H, thiophenol-C($CH_3)_3$); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.55 (C=O), 149.68 (C^5-thiophenol), 135.96 (C^1-thiophenol), 132.65 (Ph-MTPA), 132.00 (C^2-thiophenol), 131.35 (C^3-thiophenol), 129.92 (Ph-MTPA), 129.67 ($-\underline{C}H{=}CH_2$), 128.81 (C^6-thiophenol), 128.47 (2C, Ph-MTPA), 127.45 (2C, Ph-MTPA), 124.64 (C^4-thiophenol), 120.33 ($-CH{=}\underline{C}H_2$), 114.63 (quaternary-C), 91.09 (C-1), 86.05 (C-4), 85.11 (C-2), 80.85 (C-3), 75.36 (C-5), 55.75 ($-OCH_3$), 34.52 (thiophenol-$\underline{C}(CH_3)_3$), 31.30 (3C, thiophenol-C($\underline{C}H_3)_3$), 27.07 (isopropylidene-CH_3), 25.27 (isopropylidene-CH_3), 20.24 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.34 (m, 2H, Ar); HRMS (ESI^+) calcd. for $C_{31}H_{37}F_3NaO_6S^+$ 617.2155, found 617.2165.

4.2.22. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)allyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**9aS**)

According to general procedure *C*, compound **9a** (10 mg, 27 μmol, 1 equiv.) yielded compound **9aS** (colorless oil, 9 mg, 15 μmol, 57%). Compound **9aS**: R_f 0.56 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.39 min; $[\alpha]_D = -26$ (20 °C, c = 0.31, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.53–7.46 (m, 3H, Ar, H^6-thiophenol), 7.39–7.27 (m, 3H, Ar), 7.19 (m, 1H, H^3-thiophenol), 7.13 (m, 1H, H^4-thiophenol), 5.74 (m, 1H, $-\underline{C}H{=}CH_2$), 5.63 (m, 1H, H-5), 5.53 (d, *J* = 2.8 Hz, 1H, H-1), 5.43 (m, 2H, $-CH{=}\underline{C}H_2$), 4.73 (dd, *J* = 6.3, 2.8 Hz, 1H, H-2), 4.58 (dd, *J* = 6.3, 3.1 Hz, 1H, H-3), 4.23 (dd, *J* = 8.5, 3.1 Hz, 1H, H-4), 3.41 (s, 3H, $-OCH_3$), 2.36 (s, 3H, thiophenol-CH_3), 1.51 (s, 3H, isopropylidene-CH_3), 1.32 (s, 3H, isopropylidene-CH_3), 1.28 (s, 9H, thiophenol-C($CH_3)_3$); ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.40 (C=O), 149.62 (C^5-thiophenol), 136.34 (C^1-

thiophenol), 132.27 (Ph-MTPA), 131.97 (C^2-thiophenol), 130.56 (C^3-thiophenol), 130.16 (−CH=CH_2), 129.45 (Ph-MTPA), 128.26 (2C, Ph-MTPA), 128.21 (C^6-thiophenol), 127.29 (2C, Ph-MTPA), 124.67 (C^4-thiophenol), 122.23 (−CH=CH_2), 114.29 (quaternary-C), 90.84 (C-1), 86.23 (C-4), 85.50 (C-2), 81.15 (C-3), 76.91 (C-5), 55.62 (−OCH_3), 34.47 (thiophenol-C$(CH_3)_3$), 31.27 (3C, thiophenol-C$(CH_3)_3$), 27.06 (isopropylidene-CH_3), 25.35 (isopropylidene-CH_3), 20.21 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.52; HRMS (ESI^+) calcd. for $C_{31}H_{37}F_3NaO_6S^+$ 617.2155, found 617.2163.

4.2.23. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)allyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**9bR**)

According to general procedure *C*, compound **9b** (10 mg, 27 μmol, 1 equiv.) yielded compound **9bR** (colorless oil, 10 mg, 17 μmol, 64%). Compound **9bR**: R_f 0.58 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.71 min; $[\alpha]_D$ = −40 (20 °C, c = 0.25, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.60–7.53 (m, 2H, Ar), 7.51 (m, 1H, H^6-thiophenol), 7.41–7.31 (m, 3H, Ar), 7.18 (m, 1H, H^3-thiophenol), 7.11 (m, 1H, H^4-thiophenol), 5.94 (m, 1H, −CH=CH_2), 5.58 (m, 2H, −CH=CH_2), 5.45 (m, 1H, H-5), 5.34 (d, *J* = 3.3 Hz, 1H, H-1), 4.33 (dd, *J* = 6.2, 2.3 Hz, 1H, H-3), 4.29 (m, 2H, H-2, H-4), 3.51 (s, 3H, −OCH_3), 2.37 (s, 3H, thiophenol-CH_3), 1.47 (s, 3H, isopropylidene-CH_3), 1.28 (s, 9H, thiophenol-C$(CH_3)_3$), 1.22 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.67 (C=O), 149.64 (C^5-thiophenol), 136.00 (C^1-thiophenol), 133.10 (C^2-thiophenol), 132.33 (Ph-MTPA), 131.03 (C^3-thiophenol), 129.93 (−CH=CH_2), 129.56 (Ph-MTPA), 128.43 (C^6-thiophenol), 128.35 (2C, Ph-MTPA), 127.36 (2C, Ph-MTPA), 124.49 (C^4-thiophenol), 122.28 (−CH=CH_2), 113.94 (quaternary-C), 92.18 (C-1), 86.10 (C-4), 85.43 (C-2), 81.38 (C-3), 77.15 (C-5), 55.77 (−OCH_3), 34.49 (thiophenol-C$(CH_3)_3$), 31.28 (3C, thiophenol-C$(CH_3)_3$), 27.07 (isopropylidene-CH_3), 25.19 (isopropylidene-CH_3), 20.26 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.96; HRMS (ESI^+) calcd. for $C_{31}H_{37}F_3NaO_6S^+$ 617.2155, found 617.2169.

4.2.24. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)allyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**9bS**)

According to general procedure *C*, compound **9b** (10 mg, 27 μmol, 1 equiv.) yielded compound **9bS** (colorless oil, 8 mg, 13 μmol, 51%). Compound **9bS**: R_f 0.61 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.42 min; $[\alpha]_D$ = −25 (20 °C, c = 0.31, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.56 (m, 3H, Ar, H^6-thiophenol), 7.41 (m, 3H, Ar), 7.19 (m, 1H, H^3-thiophenol), 7.11 (m, 1H, H^4-thiophenol), 5.91–5.78 (m, 2H, H-5, −CH=CH_2), 5.41 (m, 1H, −CH=CH_2), 5.37 (d, *J* = 3.3 Hz, 1H, H-1), 5.33 (m, 1H, −CH=CH_2), 4.63 (dd, *J* = 6.5, 3.3 Hz, 1H, H-2), 4.56 (dd, *J* = 6.4, 2.5 Hz, 1H, H-3), 4.17 (dd, *J* = 7.0, 2.5 Hz, 1H, H-4), 3.56 (s, 3H, −OCH_3), 2.36 (s, 3H, thiophenol-CH_3), 1.48 (s, 3H, isopropylidene-CH_3), 1.29 (s, 9H, thiophenol-C$(CH_3)_3$), 1.28 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.57 (C=O), 149.62 (C^5-thiophenol), 135.81 (C^1-thiophenol), 132.76 (Ph-MTPA), 132.06 (C^2-thiophenol), 131.73 (C^3-thiophenol), 129.86 (Ph-MTPA), 129.63 (−CH=CH_2), 128.68 (C^6-thiophenol), 128.45 (2C, Ph-MTPA), 127.47 (2C, Ph-MTPA), 124.47 (C^4-thiophenol), 121.19 (−CH=CH_2), 114.20 (quaternary-C), 91.40 (C-1), 86.34 (C-4), 85.28 (C-2), 81.07 (C-3), 75.23 (C-5), 55.57 (−OCH_3), 34.50 (thiophenol-C$(CH_3)_3$), 31.29 (3C, thiophenol-C$(CH_3)_3$), 26.89 (isopropylidene-CH_3), 25.10 (isopropylidene-CH_3), 20.19 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.38; HRMS (ESI^+) calcd. for $C_{31}H_{37}F_3NaO_6S^+$ 617.2155, found 617.2156.

4.2.25. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)but-3-en-1-yl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**12aR**)

According to general procedure *C*, compound **12a** (10 mg, 27 μmol, 1 equiv.) yielded compound **12aR** (colorless oil, 3 mg, 4.9 μmol, 19%). Compound **12aR**: R_f 0.59 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.62 min; $[\alpha]_D$ = −6.6 (20 °C, c = 0.23, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.68–7.58 (m, 2H, Ar), 7.56 (m, 1H, H^6-thiophenol), 7.39 (m, 3H, Ar), 7.18 (m, 1H, H^3-thiophenol), 7.11 (m, 1H, H^4-thiophenol), 5.79 (m, 1H, −CH_2CH=CH_2), 5.21 (d, *J* = 4.3 Hz, 1H, H-1), 5.18 (m, 2H, −CH_2CH=CH_2), 5.14 (m, 1H, H-5), 4.30 (dd, *J* = 3.8, 2.0 Hz, 1H, H-2), 4.05 (dd, *J* = 6.1, 2.0 Hz, 1H, H-3), 3.92 (dd, *J* = 6.1, 4.2 Hz, 1H, H-4), 3.64 (s, 3H, −OCH_3), 2.68 (m, 1H, −CH_2CH=CH_2), 2.57 (m, 1H, −CH_2CH=CH_2), 2.38 (s, 3H, thiophenol-CH_3), 1.43 (s, 3H, isopropylidene-CH_3), 1.29 (s, 9H, thiophenol-C$(CH_3)_3$), 1.12 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.69 (C=O), 149.14 (C^5-thiophenol), 135.28 (C^1-thiophenol), 133.48 (Ph-MTPA), 132.17 (C^2-thiophenol), 131.51 (C^3-thiophenol), 129.33 (Ph-MTPA), 129.15 (−CH_2CH=CH_2), 127.93 (3C, Ph-MTPA; C^6-thiophenol), 126.57 (2C, Ph-MTPA), 123.80 (C^4-thiophenol), 118.97 (−CH_2CH=CH_2), 113.27 (quaternary-C), 92.44 (C-1), 84.75 (C-4), 83.90 (C-2), 81.18 (C-3), 75.55 (C-5), 55.68 (−OCH_3), 34.27 (−CH_2CH=CH_2), 34.01 (thiophenol-C$(CH_3)_3$), 30.83 (3C, thiophenol-C$(CH_3)_3$), 26.65 (isopropylidene-CH_3), 24.59 (isopropylidene-CH_3), 19.75 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.66; HRMS (ESI^+) calcd. for $C_{32}H_{39}F_3NaO_6S^+$ 631.2312, found 631.2317.

4.2.26. (S)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)but-3-en-1-yl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**12aS**)

According to general procedure *C*, compound **12a** (10 mg, 27 μmol, 1 equiv.) yielded compound **12aS** (colorless oil, 10 mg, 16 μmol, 62%). Compound **12aS**: R_f 0.54 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.56 min; $[\alpha]_D$ = −10 (20 °C, c = 0.28, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.62–7.54 (m, 2H, Ar), 7.52 (m, 1H, H^6-thiophenol), 7.44–7.39 (m, 1H, Ar), 7.37–7.32 (m, 2H, Ar), 7.20 (m, 1H, H^3-thiophenol), 7.12 (m, 1H, H^4-thiophenol), 5.66 (m, 1H, −CH_2CH=CH_2), 5.34–5.25 (m, 2H, H-1, H-5), 5.07 (m, 1H, −CH_2CH=CH_2), 5.02 (m, 1H, −CH_2CH=CH_2), 4.55 (dd, *J* = 6.4, 3.9 Hz, 1H, H-2), 4.48 (dd, *J* = 6.4, 3.5 Hz, 1H, H-3), 4.20 (dd, *J* = 6.6, 3.5 Hz, 1H, H-4), 3.45 (s, 3H, −OCH_3), 2.56 (m, 1H, −CH_2CH=CH_2), 2.39 (m, 4H, −CH_2CH=CH_2, thiophenol-CH_3), 1.51 (s, 3H, isopropylidene-CH_3), 1.31 (s, 3H, isopropylidene-CH_3), 1.27 (s, 9H, thiophenol-C$(CH_3)_3$); ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.56 (C=O), 149.16 (C^5-thiophenol), 136.07 (C^1-thiophenol), 131.93 (Ph-MTPA), 131.51 (C^2-thiophenol), 131.27 (C^3-thiophenol), 129.54 (Ph-MTPA), 129.06 (−CH_2CH=CH_2), 128.50 (C^6-thiophenol), 127.88 (2C, Ph-MTPA), 127.13 (2C, Ph-MTPA), 124.28 (C^4-thiophenol), 118.80 (−CH_2CH=CH_2), 114.17 (quaternary-C), 90.39 (C-1), 84.63 (C-4), 84.47 (C-2), 80.72 (C-3), 74.98 (C-5), 55.02 (−OCH_3), 34.20 (−CH_2CH=CH_2), 33.99 (thiophenol-C$(CH_3)_3$), 30.80 (3C, thiophenol-C$(CH_3)_3$), 26.77 (isopropylidene-CH_3), 24.89 (isopropylidene-CH_3), 19.80 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.10; HRMS (ESI^+) calcd. for $C_{32}H_{39}F_3NaO_6S^+$ 631.2312, found 631.2321.

4.2.27. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)ethyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**12bR**)

According to general procedure *C*, compound **12b** (10 mg, 27 μmol, 1 equiv.) yielded compound **12bR** (colorless oil, 5 mg, 8.2 μmol, 31%). Compound **12bR**: R_f 0.67 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.71 min; $[\alpha]_D$ = −18 (20 °C, c = 0.33,

$CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.61 (m, 2H, Ar), 7.57 (m, 1H, H^6-thiophenol), 7.44–7.37 (m, 3H, Ar), 7.20 (m, 1H, H^3-thiophenol), 7.13 (m, 1H, H^4-thiophenol), 5.60 (m, 1H, $-CH_2\underline{C}H=CH_2$), 5.51 (m, 1H, H-5), 5.46 (d, J = 2.5 Hz, 1H, H-1), 4.96 (m, 2H, $-CH_2CH=C\underline{H}_2$), 4.74–4.65 (m, 2H, H-2, H-3), 4.16 (dd, J = 7.9, 2.1 Hz, 1H, H-4), 3.59 (s, 3H, $-OCH_3$), 2.47 (m, 1H, $-C\underline{H}_2CH=CH_2$), 2.34 (m, 4H, $-C\underline{H}_2CH=CH_2$, thiophenol-CH_3), 1.52 (s, 3H, isopropylidene-CH_3), 1.31 (s, 3H, isopropylidene-CH_3), 1.30 (s, 9H, thiophenol-C$(CH_3)_3$); ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.54 (C=O), 149.24 (C^5-thiophenol), 135.18 (C^1-thiophenol), 132.11 (Ph-MTPA), 131.61 (C^2-thiophenol), 131.16 (C^3-thiophenol), 129.52 (Ph-MTPA), 129.13 ($-CH_2\underline{C}H=CH_2$), 127.94 (2C, Ph-MTPA), 127.64 (C^6-thiophenol), 126.97 (2C, Ph-MTPA), 123.99 (C^4-thiophenol), 118.72 ($-CH_2CH=\underline{C}H_2$), 113.82 (quaternary-C), 90.31 (C-1), 85.17 (C-4), 85.02 (C-2), 80.97 (C-3), 73.96 (C-5), 55.19 ($-OCH_3$), 34.77 ($-\underline{C}H_2CH=CH_2$), 34.05 (thiophenol-$\underline{C}(CH_3)_3$), 30.83 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.42 (isopropylidene-CH_3), 24.65 (isopropylidene-CH_3), 19.67 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.14; HRMS (ESI^+) calcd. for $C_{32}H_{39}F_3NaO_6S^+$ 631.2312, found 631.2323.

4.2.28. (R)-1-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)but-3-en-1-yl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**12bS**)

According to general procedure *C*, compound **12b** (10 mg, 27 μmol, 1 equiv.) yielded compound **12bS** (colorless oil, 3 mg, 4.9 μmol, 19%). Compound **12bS**: R_f 0.65 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.65 min; $[\alpha]_D$ = −10 (20 °C, c = 0.23, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.64–7.50 (m, 3H, Ar, H^6-thiophenol), 7.45–7.34 (m, 3H, Ar), 7.19 (m, 1H, H^3-thiophenol), 7.12 (m, 1H, H^4-thiophenol), 5.72 (m, 1H, $-CH_2\underline{C}H=CH_2$), 5.52 (m, 1H, H-5), 5.46 (d, J = 2.8 Hz, 1H, H-1), 5.07 (m, 2H, $-CH_2CH=C\underline{H}_2$), 4.67 (dd, J = 6.4, 2.8 Hz, 1H, H-2), 4.51 (dd, J = 6.4, 2.2 Hz, 1H, H-3), 4.11 (dd, J = 8.4, 2.3 Hz, 1H, H-4), 3.55 (s, 3H, $-OCH_3$), 2.58 (m, 1H, $-C\underline{H}_2CH=CH_2$), 2.39 (m, 4H, $-C\underline{H}_2CH=CH_2$, thiophenol $-CH_3$), 1.47 (s, 3H, isopropylidene-CH_3), 1.30 (s, 9H, thiophenol-C$(CH_3)_3$), 1.29 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 166.09 (C=O), 149.70 (C^5-thiophenol), 135.53 (C^1-thiophenol), 132.73 (Ph-MTPA), 132.06 (C^2-thiophenol), 131.98 (C^3-thiophenol), 129.99 (Ph-MTPA), 129.64 ($-CH_2\underline{C}H=CH_2$), 128.42 (2C, Ph-MTPA), 127.88 (C^6-thiophenol), 127.50 (2C, Ph-MTPA), 124.36 (C^4-thiophenol), 119.23 ($-CH_2CH=\underline{C}H_2$), 113.94 (quaternary-C), 91.05 (C-1), 85.68 (C-4), 85.50 (C-2), 81.49 (C-3), 74.25 (C-5), 55.70 ($-OCH_3$), 35.38 ($-\underline{C}H_2CH=CH_2$), 34.55 (thiophenol-$\underline{C}(CH_3)_3$), 31.33 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.75 (isopropylidene-CH_3), 24.97 (isopropylidene-CH_3), 20.15 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.25; HRMS (ESI^+) calcd. for $C_{32}H_{39}F_3NaO_6S^+$ 631.2312, found 631.2310.

4.2.29. (S)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl) methyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**13aR**)

According to general procedure *C*, compound **13a** (10 mg, 26 μmol, 1 equiv.) yielded compound **13aR** (colorless oil, 5 mg, 7.7 μmol, 33%). Compound **13aR**: R_f 0.52 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.48 min; $[\alpha]_D$ = −12 (20 °C, c = 0.23, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.56–7.45 (m, 5H, Ar), 7.43–7.35 (m, 4H, Ar), 7.35–7.30 (m, 2H, Ar), 7.19 (m, 1H, H^3-thiophenol), 7.13 (m, 1H, H^4-thiophenol), 6.15 (d, J = 6.8 Hz, 1H, H-5), 5.47 (d, J = 2.9 Hz, 1H, H-1), 4.56 (dd, J = 6.8, 2.1 Hz, 1H, H-4), 4.40 (dd, J = 6.2, 3.0 Hz, 1H, H-2), 4.34 (dd, J = 6.2, 2.1 Hz, 1H, H-3), 3.41 (s, 3H, $-OCH_3$), 2.41 (s, 3H, thiophenol-CH_3), 1.47 (s, 3H, isopropylidene-CH_3), 1.28 (s, 9H, thiophenol-C$(CH_3)_3$), 1.21 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.79 (C=O), 149.72 (C^5-thiophenol), 135.44 (C^1-thiophenol), 135.18 (Ph), 133.47 (Ph-MTPA), 132.38 (C^2-thiophenol), 129.92 (Ph-MTPA), 129.51 (C^3-thiophenol), 129.20 (Ph), 128.73 (2C, Ph-MTPA), 128.31 (2C, Ph), 128.29 (2C, Ph), 127.57 (C^6-thiophenol), 127.43 (2C, Ph-MTPA), 124.21 (C^4-thiophenol), 113.76 (quaternary-C), 92.22 (C-1), 87.43 (C-4), 85.67 (C-2), 81.54 (C-3), 78.21 (C-5), 55.74 ($-OCH_3$), 34.52 (thiophenol-$\underline{C}(CH_3)_3$), 31.29 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.99 (isopropylidene-CH_3), 25.19 (isopropylidene-CH_3), 20.21 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.72; HRMS (ESI^+) calcd. for $C_{35}H_{39}F_3NaO_6S^+$ 667.2312, found 667.2319.

4.2.30. (S)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl) methyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**13aS**)

According to general procedure *C*, compound **13a** (9.5 mg, 26 μmol, 1 equiv.) yielded compound **13aS** (colorless oil, 14 mg, 22 μmol, 93%). Compound **13aS**: R_f 0.54 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.49 min; $[\alpha]_D$ = −42 (20 °C, c = 0.34, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.53 (m, 1H, H^6-thiophenol), 7.41–7.31 (m, 4H, Ar), 7.31–7.25 (m, 4H, Ar), 7.24–7.14 (m, 4H, Ar, H^3-thiophenol, H^4-thiophenol), 6.15 (d, J = 9.3 Hz, 1H, H-5), 5.72 (d, J = 2.2 Hz, 1H, H-1), 4.81 (dd, J = 6.1, 2.2 Hz, 1H, H-2), 4.57 (dd, J = 9.4, 2.5 Hz, 1H, H-4), 4.50 (dd, J = 6.2, 2.5 Hz, 1H, H-3), 3.37 (s, 3H, $-OCH_3$), 2.41 (s, 3H, thiophenol-CH_3), 1.49 (s, 3H, isopropylidene-CH_3), 1.31 (s, 9H, thiophenol-C$(CH_3)_3$), 1.24 (s, 3H, isopropylidene-CH_3); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.32 (C=O), 149.66 (C^5-thiophenol), 135.84 (C^1-thiophenol), 134.72 (Ph), 132.30 (C^2-thiophenol), 132.20 (Ph-MTPA), 130.25 (C^3-thiophenol), 129.29 (2C, Ph-MTPA; Ph), 128.77 (2C, Ph-MTPA), 128.20 (2C, Ph), 128.14 (2C, Ph), 127.26 (C^6-thiophenol), 127.18 (2C, Ph-MTPA), 124.41 (C^4-thiophenol), 113.82 (quaternary-C), 91.16 (C-1), 87.83 (C-4), 85.80 (C-2), 81.32 (C-3), 78.67 (C-5), 55.71 ($-OCH_3$), 34.55 (thiophenol-$\underline{C}(CH_3)_3$), 31.32 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.92 (isopropylidene-CH_3), 25.28 (isopropylidene-CH_3), 20.20 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.77; HRMS (ESI^+) calcd. for $C_{35}H_{39}F_3NaO_6S^+$ 667.2312, found 667.2321.

4.2.31. (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl) methyl (R)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**13bR**)

According to general procedure *C*, compound **13b** (10 mg, 27 μmol, 1 equiv.) yielded compound **13bR** (colorless oil, 13 mg, 20 μmol, 86%). Compound **13bR**: R_f 0.64 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.64 min; $[\alpha]_D$ = −33 (20 °C, c = 0.49, $CHCl_3$); ^1H NMR (400 MHz, Chloroform-*d*) δ 7.44–7.27 (m, 6H, Ar), 7.27–7.17 (m, 5H, Ar), 7.15 (m, 1H, H^3-thiophenol), 7.11 (m, 1H, H^4-thiophenol), 6.22 (d, J = 8.3 Hz, 1H, H-5), 5.42 (d, J = 3.0 Hz, 1H, H-1), 4.84 (dd, J = 6.3, 2.3 Hz, 1H, H-3), 4.77 (dd, J = 6.3, 3.0 Hz, 1H, H-2), 4.47 (dd, J = 8.3, 2.3 Hz, 1H, H-4), 3.58 (s, 3H, $-OCH_3$), 2.35 (s, 3H, thiophenol-CH_3), 1.49 (s, 3H, isopropylidene-CH_3), 1.33 (s, 3H, isopropylidene-CH_3), 1.16 (s, 9H, thiophenol-C$(CH_3)_3$); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.38 (C=O), 149.65 (C^5-thiophenol), 135.52 (C^1-thiophenol), 135.05 (Ph), 133.06 (C^2-thiophenol), 131.75 (Ph-MTPA), 129.77 (C^3-thiophenol), 129.56 (Ph-MTPA), 128.64 (Ph), 128.32 (2C, Ph-MTPA; 2C, Ph), 127.81 (2C, Ph), 127.53 (C^6-thiophenol), 127.40 (2C, Ph-MTPA), 124.16 (C^4-thiophenol), 114.22 (quaternary-C), 91.08 (C-1), 87.45 (C-4), 85.65 (C-2), 81.76 (C-3), 76.93 (C-5), 55.79 ($-OCH_3$), 34.40 (thiophenol-$\underline{C}(CH_3)_3$), 31.20 (3C, thiophenol-C($\underline{C}H_3)_3$), 26.92 (isopropylidene-CH_3), 25.21 (isopropylidene-CH_3), 20.14 (thiophenol-CH_3), $\underline{C}F_3$ and $\underline{C}CF_3$ were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.55; HRMS (ESI^+) calcd. for $C_{35}H_{39}F_3NaO_6S^+$ 667.2312, found 667.2310.

*4.2.32. (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) thio)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl) methyl (S)-3,3,3-trifluoro-2-methoxy-2-phenylpropanoate (**13bS**)*

According to general procedure *C*, compound **13b** (10 mg, 27 μmol, 1 equiv.) yielded compound **13bS** (colorless oil, 10 mg, 16 μmol, 66%). Compound **13bS**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); HPLC t_R 5.59 min; $[\alpha]_D = -29$ (20 °C, c = 0.47, $CHCl_3$); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.48–7.43 (m, 2H, Ar), 7.42–7.31 (m, 6H, Ar), 7.28–7.24 (m, 3H, Ar), 7.19–7.09 (m, 2H, H^3-thiophenol, H^4-thiophenol), 6.29 (d, *J* = 9.2 Hz, 1H, H-5), 5.46 (d, *J* = 2.6 Hz, 1H, H-1), 4.78 (dd, *J* = 6.3, 2.5 Hz, 1H, H-2), 4.65 (dd, *J* = 6.3, 1.9 Hz, 1H, H-3), 4.53 (dd, *J* = 9.1, 1.9 Hz, 1H, H-4), 3.46 (s, 3H, $-OCH_3$), 2.37 (s, 3H, thiophenol-CH_3), 1.46 (s, 3H, isopropylidene-CH_3), 1.29 (s, 3H, isopropylidene-CH_3), 1.16 (s, 9H, thiophenol-C(CH_3)$_3$); ^{13}C NMR (151 MHz, Chloroform-*d*) δ 165.68 (C=O), 149.61 (C^5-thiophenol), 135.85 (C^1-thiophenol), 134.90 (C, Ph), 133.19 (Ph-MTPA), 132.09 (C^2-thiophenol), 129.72 (Ph-MTPA), 129.62 (C^3-thiophenol), 128.81 (C^6-thiophenol), 128.46 (2C, Ph-MTPA), 128.42 (2C, Ph), 128.23 (2C, Ph), 127.39 (2C, Ph-MTPA; C, Ph), 124.03 (C^4-thiophenol), 113.78 (quaternary-C), 91.48 (C-1), 87.53 (C-4), 85.78 (C-2), 81.84 (C-3), 76.35 (C-5), 55.56 ($-OCH_3$), 34.39 (thiophenol-C(CH_3)$_3$), 31.20 (thiophenol-C(CH_3)$_3$), 26.72 (isopropylidene-CH_3), 24.98 (isopropylidene-CH_3), 20.14 (thiophenol-CH_3), CF_3 and CCF_3 were not found; ^{19}F NMR (471 MHz, Chloroform-*d*) δ −71.27; HRMS (ESI^+) calcd. for $C_{35}H_{39}F_3NaO_6S^+$ 667.2312, found 667.2319.

*4.2.33. (R)-((3aR,4R,6S,6aR)-6-((5-(tert-butyl)-2-methylphenyl) sulfonyl)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(phenyl)methanol (**17**)*

Compound **13b** (50 mg, 117 μmol, 1 equiv.) was dissolved in DCM (1 mL), cooled with ice bath, and treated with a solution of mCPBA (60 mg, 350 μmol, 3 equiv.) in DCM (1 mL). The reaction mixture was then stirred overnight at RT, quenched with sat. aq. $NaHCO_3$ and sat. aq. $Na_2S_2O_3$. The organic phase was washed with brine, concentrated, and purified with flash chromatography (on silica gel with 60–90 °C petroleum ether: EtOAc = 10:1) to give product **17** (white solid, 36 mg, 78 μmol, 67%). Crystal of **17** suitable for X-ray analysis was obtained from TBME and 60–90 °C petroleum ether. Compound **17**: R_f 0.63 (ethyl acetate: 60–90 °C petroleum ether, 1/5); mp. 126.5–128.8 °C (TBME/60–90 °C petroleum ether); HPLC t_R 4.28 min; $[\alpha]_D = -39$ (20 °C, c = 0.38, $CHCl_3$); ^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.01 (m, 1H, H^6-thiophenol), 7.59 (m, 1H, H^4-thiophenol), 7.42 (m, 2H, Ph), 7.38 (m, 2H, Ph), 7.33–7.27 (m, 2H, Ph, H^3-thiophenol), 5.41 (dd, *J* = 6.0, 3.7 Hz, 1H, H-2), 5.05 (m, 1H, H-5), 4.98 (d, *J* = 3.8 Hz, 1H, H-1), 4.87 (dd, *J* = 6.0, 1.4 Hz, 1H, H-3), 4.67 (t, *J* = 1.7 Hz, 1H, H-4), 2.70 (s, 3H, thiophenol-CH_3), 1.47 (s, 3H, isopropylidene-CH_3), 1.34 (s, 9H, isopropylidene-(CH_3)$_3$), 1.29 (s, 3H, isopropylidene-CH_3), CF_3 and CCF_3 were not found; ^{13}C NMR (126 MHz, Chloroform-d) δ 150.44 (C^5-thiophenol), 138.69 (1C, Ph), 136.32 (C^1-thiophenol), 134.48 (C^2-thiophenol), 133.05 (C^3-thiophenol), 131.89 (C^6-thiophenol), 128.80 (2C, Ph), 128.11 (1C, Ph), 127.91 (C4-thiophenol), 126.00 (2C, Ph), 114.04 (quaternary-C), 100.23 (C-1), 93.90 (C-4), 80.89 (C-2), 80.05 (C-3), 73.57 (C-5), 34.95 (thiophenol-C(CH_3)$_3$), 31.31 (thiophenol-C(CH_3)$_3$), 27.42 (isopropylidene-CH_3), 25.27 (isopropylidene-CH_3), 20.55 (thiophenol-CH_3); HRMS (ESI^+) calcd. for $C_{25}H_{32}O_6SNa^+$ 483.1817, found 483.1810.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (81673309, 81273368), National Science & Technology Major Project "Key New Drug Creation and Manufacturing Program", China (2014ZX09507-002), and "Personalized Medicines - Molecular Signature-based Drug Discovery and Development", Strategic Priority Research Program of the Chinese Academy of Sciences, Grant No. XDA12020310.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.tet.2017.03.013.

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