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Studies toward the oxidative and reductive activation of C-S bonds in 2'-S-aryl-2'-thiouridine derivatives

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Abstract

Studies directed toward the oxidative and reductive desulfurization of readily available 2'-S-aryl-2'-thiouridine derivatives were investigated with the prospect to functionalize the C2'-position of nucleosides. The oxidative desulfurization-difluorination strategy was successful on 2-(arylthio)alkanoate surrogates, while extension of the combination of oxidants and fluoride sources was not an efficient fluorination protocol when applied to 2'-S-aryl-2'-thiouridine derivatives, resulting mainly in C5-halogenation of the pyrimidine ring and C2'-monofluorination without desulfurization. Cyclic voltammetry of 2'-arylsulfonyl-2'-deoxyuridines and their 2'-fluorinated analogues showed that cleavage of the arylsulfone moiety could occur, although at relatively high cathodic potentials. While reductive-desulfonylation of 2'-arylsulfonyl-2'-deoxyuridines with organic electron donors (OEDs) gave predominantly base-induced furan type products, chemical (OED) and electrochemical reductive-desulfonylation of the α -fluorosulfone derivatives yielded the 2'-deoxy-2'-fluorouridine and 2',3'-didehydro-2',3'-dideoxy-2'-fluorouridine derivatives. These results provided good evidence of the generation of a C2'-anion through carbon-sulfur bond cleavage, opening new horizons for the reductive-functionalization approaches in nucleosides.

Keywords: Cyclic Voltammetry, Desulfurization-Fluorination, Fluorination, Nucleosides, Organic Electron Donors, Reductive Desulfonylation

Introduction

Introduction of fluorine atom(s) into nucleosides dramatically changes their electronic and steric properties, giving them a wide range of biological activity.¹⁻³ Prominent examples of C2' fluorinated nucleosides with potent biological activities include anticancer drugs gemcitabine,⁴⁻⁶ and clofarabine;^{7,8} and hepatitis C virus drug sofosbuvir.^{9,10} In the last 40 years, numerous methods for the incorporation of fluorine atoms into organic molecules have been developed, as summarized in excellent reviews.¹¹⁻¹⁶ Despite these developments, construction of the tertiary fluorinated stereocenter at the sugar C2' (e.g. sofosbuvir) has been still challenging.¹⁷

Oxidative desulfurization-(di)fluorination is an important fluorination protocol for the preparation of fluoro organic compounds.^{16,18} Various reagents or reagent-combinations developed for this approach are known and are based mostly on the combination of an oxidant [e.g., *N*-halosuccinimides (NBS, NIS) or 1,3-dibromo-5,5-dimethylhydantoin (DBH)] and a potentially hazardous fluoride source [e.g., HF-pyridine,¹⁹⁻²¹ iodine pentafluoride (IF₅),²²⁻²⁴ air- and moisture-stable IF₅-pyridine-HF reagent,^{25,26} or BrF₃-KHF₂].²⁷ In addition to these chemical approaches, direct and indirect (with the use of a redox mediator) electrochemical approaches have been developed for some oxidative desulfurization-(di)fluorination reactions, using different sources of fluorinating reagents, either in organic solvents or in Ionic Liquids (ILs).²⁸⁻³¹

Although, chemical and electrochemical-induced reductive desulfonation reactions have been known for years,³²⁻⁴⁰ in nucleoside series they have been limited to reductive dehalogenation or desulfonation protocols *en route* to 2',3'-dideoxy-2',3'-didehydro nucleosides.⁴¹⁻⁴⁷ Reductive desulfonation/functionalization (including (di)fluorination) strategies in nucleosides are to the best of our knowledge, unknown processes. Our goal was to investigate alternative methodologies for the modification of nucleosides at C2' position utilizing 2'-*S*-aryl-2'-thionucleosides as convenient substrates to access well-known fluoro nucleosides (e.g., gemcitabine or PSI 6130, a core of Sofosbuvir). Herein we report studies on the reactivity of 2'-*S*-aryl-2'-thiouridine substrates (type I, Figure 1) with respect to oxidation processes and 2'-arylsulfonyl-2'-deoxyuridine (type II) with respect to reductive processes. The oxidative fluorination processes are envisioned to proceed via desulfurization-difluorination of the uridine-2'-thioethers (substrate I, X = H) or desulfurization-fluorination of uridine α -fluorothioethers (substrate I, X = F) using halonium ion (Br⁺, I⁺) reagents as oxidants and a nucleophilic fluorine source (F⁻) for quenching the intermediary C2'-carbocation. The reductive fluorination processes are proposed to proceed via cleavage of the sulfonyl moiety (from substrate II, X = H or F) with single electron transfer reagents or electrochemically and quenching the resultant C2'-carbanion with electrophiles such as F⁺, H⁺, CH₃⁺, etc.

Figure 1. Proposed pathways for the C2'-functionalization of uridine derivatives

Results and Discussion

Because of the lack of examples for desulfurization-difluorination reactions of aryl-alkyl thioethers with the arylthio group attached to a secondary internal carbon atom, we initially performed model studies with α -arylthio substituted esters (e.g., **2**; Scheme 1) that mimic the 2'-position of the ribose in the nucleoside targets (e.g., **I**, X = H). Using the methodology developed by *Haufe et al.*^{20,21} we found that treatment of ethyl 2-(phenylthio)octanoate **2** with DBH (3 eq.) and Olah's reagent (Py.9HF, 6 eq.) in CH₂Cl₂ at 35°C for 2 h, showed 90% conversion to 2,2-difluorooctanoate **5b** (¹H NMR, ¹⁹F NMR; Scheme 1). The *para*-chlorophenylthio substituted ester **3** provided 2,2-difluorohexanoate **5a** in almost quantitative yield in only 1 h, whereas *para*-methoxyphenylthio ester **4** required 16 h to show 70% conversion to **5a**.⁴⁸ These results illustrated that 4-chlorophenyl thioethers were better substrates for these difluorination reactions than corresponding phenyl and 4-methoxyphenyl thioethers, as noted also by *Haufe, et al.* for the primary alkyl-aryl thioethers.²¹ The EDGs on the phenyl ring are believed to stabilize the cationic charge on the resonance-stabilized carbenium-sulfonium ion intermediate and thus promote the first fluorination step; whereas EWGs are assumed to ease the elimination of arylsulfenyl bromide in the last step and therefore promote the *critical* second fluorination step.²¹ The DBH was proven to be more effective than other halogen oxidants (NBS, NIS) in these reactions.⁴⁸

Scheme 1. Desulfurization-difluorinations of α -thioesters **2-4**.

Despite successful desulfurization-difluorination strategy with 2-arylthioalkanoate surrogates, our attempts to extend this protocol to sugars and nucleosides met with only limited success. Thus, treatment of (*S*)-(+)-2-phenylthio-4-benzyloxymethyl-4-butanolide⁴⁹ with DBH (4 equiv.)/Py.9HF (8 equiv.)/CH₂Cl₂/35 °C/15 h gave complex reaction mixture.⁴⁸ Also, attempted fluorination of readily available⁵⁰ 2'-*S*-aryl-2'-thiouridine analogues of type **6**⁵¹ (Scheme 2) or 2'-*S*-aryl-2'-fluoro-2'-thiouridine analogues of type **8**⁵¹ (Scheme 3) with Py.9HF/DBH failed to give 2',2'-difluoro products yielding instead 5-brominated⁵² products as well as the corresponding sulfoxides and/or α -fluoro sulfoxides, among other byproducts. Installing different protection groups on sugar hydroxyls (Ac, Bn) and EDG (MeO) or EWG (Cl) in phenyl ring as well as changing reaction conditions (e.g., halogen source, temperature, reaction time) did not change the outcome.⁴⁸

Interestingly, treatment of the 4-methoxyphenyl thioether **6** with NIS (2.1 eq.)/Py.9HF (3 eq.) gave the corresponding 5-iodo **7** (29%) and the α -fluorothioether **8** (12%) products (Scheme 2). Analogous treatment of sulfide **6** with NIS/DAST combination^{53,54} produced the mono- α -fluorothioether **8** in 44% isolated yield without 5-halogenation. In contrast, treatment of **6** with DBH (3 eq.)/Py.9HF (6 eq.) generated a complex reaction mixture. These results reiterate the mechanistic assumption that ring activating groups (e.g., OMe) on the aryl ring promote the first fluorination step.

Conditions A: NIS (2.1 eq), Py.9HF (3 eq); Conditions B: NIS (2.1 eq), DAST (6 eq).

Scheme 2. Attempted fluorination of 2'-*S*-(4-methoxyphenyl)-2'-thiouridine analogue **6**

Moreover, treatment of α -fluorothioether **8** with DBH/Py.9HF at -78 °C effected selective bromination of the uracil ring at the C5 position⁵² yielding the corresponding 5-bromoderivative **9** as a major product (50%), however with no indication of the *geminal* difluoro product formation (Scheme 3). Interestingly, the α -fluorothioether moiety in **9** remained intact under these *oxidative* conditions. It was previously noted that oxidation of α -fluorothioethers to the α -fluoro sulfoxides with *m*-CPBA required higher temperature and longer reaction time than conversion of the unfluorinated thioethers to the corresponding sulfoxides.⁵⁰

Scheme 3. Attempted fluorination of 2'-fluoro-2'-S-(4-methoxyphenyl)-2'-thiouridine derivative **8**

Since the *oxidative* desulfurization-fluorination approaches were not efficient protocols for the utilization of 2'-arylthiouridine derivatives as substrates for the modification of the C2'-position, we turned our attention to the development of a *reductive* desulfonylation approach. This strategy is consisted with the generation of an intermediary carbanion at the C2'-position of uridine derivatives which could be subsequently coupled to an electrophile (e.g., **II**; Figure 1). We assumed that such anion could be obtained through cleavage of the C2'-S bond in 2'-arylsulfonyl-2'-deoxyuridine substrates. Moreover, such sulfones derivatives could be conveniently synthesized by simple oxidation of the arylthiouridine substrates used for the oxidative approach.^{50,51} Reductive removal of sulfones is usually mediated by highly aggressive metal-containing reducing agents, typically alkali metals, not always compatible with the nucleoside chemistry, as they can cause side reactions on the diverse functional groups present in the molecule.³³ Instead, we opted for the use of recently reported organic electron donors (OEDs)⁵⁵⁻⁵⁷ that can selectively cleave C-SO₂ bonds by stepwise transfer of two electrons under mild reaction conditions.^{35,58} The bispyridinylidene **SED** has a redox potential of $E_{1/2}$ (DMF) = - 1.24 V vs SCE (Figure 2) and efficiently reduces sulfones *via* the formation of anion intermediates.⁵⁸ Its high tolerance to other functional groups, such as ketones, made it particularly suitable for our 2'-deoxyuridine substrates.

Figure 2. Redox potential and equilibria of bispyridinylidene **SED** named as “Super-electron donor”.

When the 2'-sulfone **10**⁵⁰ was treated at r.t. with the organic reductant **SED**, the reaction cleanly provided the furan product **11** in 95% yield after 15 min (Scheme 4). The uracil base **12** was identified (but not isolated) by ¹H NMR in the aqueous phase along with other impurities. To our surprise, cleavage of the C2'-S bond was not observed and the unexpected formation of **11** could not be explained by a sole electron-transfer mechanism. To rationalize this result, we tried the same reaction with a less powerful organic reductant, the commercially available tetrakis(dimethylamino)ethylene (**TDAE**) [$E_{1/2}$ (DMF) = - 0.62 V vs SCE]. Treatment of 2'-sulfone **10** with an excess of **TDAE** gave the 3'-acetoxy elimination product **13** (34%), the enol type (open chain sugar) product **14** (20%) and the same furan derivative **11**

(46%).

Scheme 4. Reduction studies of the acetyl-protected sulfone substrate **10** with organic donors.

Cyclic voltammetry analysis showed that sulfone derivative **10** could be reduced in two irreversible reduction steps at potentials of - 2.42 and - 2.64 V vs SCE (Figure S1, Table S1, Supporting Information), with the first reduction step (E_{pc1}) corresponding to the cleavage of the C2'-S bond with the expulsion of the *p*-methoxybenzenesulfinate. This hypothesis was confirmed by the cyclic voltammetry of an authentic sample⁵⁹ of sodium *p*-methoxybenzenesulfinate (Figure S2). While the reduction potential is in the array of redox potentials that the effective reducing power of **SED** could reportedly attain,⁶⁰ the redox potential gap between **TDAE** and **10** ($\Delta E > 1.2$ V) clearly indicates that reduction of **10** cannot be achieved by **TDAE**-promoted electron transfer. Since OEDs can act as base or as reducing agent,^{61,62} we assumed that **TDAE** initially acted as a base inducing elimination of AcOH by abstracting H2' to produce **13** (Scheme 5). Judging from the first reduction potential of **13** ($E_{pc1} = - 2.11$ V vs SCE; Table S1, Figure S3), further reduction of **13** by **TDAE** to produce **11** would also be rather difficult. One can think that **TDAE** is only acting as a base and that **13** suffers from base-induced reactions leading in turn to **14** and **11** (*base-induced pathway*, Scheme 5). The hypothesis of a basic behavior was supported by the fact that reaction of **10** with 4-dimethylaminopyridine (DMAP) led to the quantitative formation of **11**. On the other hand, in the case of **SED**, a mixed base-/electron transfer-induced mechanism could occur and rapidly lead to **11**. We assumed that under more forced reducing conditions,⁶⁰ **13** could be reduced in parallel to the base-induced reactions (*ET-induced pathway*, Scheme 5). Hence, **13** could be reduced by single-electron transfer (SET) leading to glycosidic bond cleavage, followed by trapping of the formed radical by the radical cation of the electron donor (**SED**⁺).⁶³ A last base-induced reaction would give **11** and regenerate the **SED**.

Scheme 5. Proposed "base-*versus* electron transfer-induced" mechanism for the reaction of **10** with OEDs.

Since the acetyl protection in **10** was base labile in the presence of OEDs, and prone to elimination from the intermediate C2'-carbanion, we also studied benzylated sulfone substrates. However, treatment of the fully benzylated 2'-[(4-methoxyphenyl)sulfonyl]uridine **15**⁵¹ ($E_{pc1} = -2.42$ V vs SCE; Figure S1, Table S1) with a stoichiometric amount of **SED** resulted in a similar rapid glycosidic bond cleavage producing the vinyl sulfone **16** (70%) and 3-*N*-benzyluracil **17** (69%; Scheme 6). This result indicated that the basic character of **SED** was probably predominant over its reducing character with substrates bearing a labile α -hydrogen. Treatment of **15** with an excess of **SED** gave two inseparable ribose derivatives: the vinyl sulfone **16** and the furan derivative **18** with possibly the latter being formed from **16** under reducing and/or basic conditions as proposed for **10** in Scheme 5.

Scheme 6. Reduction studies of benzyl protected sulfone substrate **15** with the **SED**

Since the α -hydrogen of 2'-sulfone substrates were too labile under the desired reductive conditions, α -fluorosulfones **19**⁵⁰ and **24**⁵¹ were chosen for the further studies. Thus, treatment of α -

fluorosulfone **19** ($E_{pc1} = -2.36$ V vs SCE; Figure S4, Table S1) with the **SED** reagent at room temperature gave the mono 3'-deacetylated product **20** (45% conversion) along with unchanged starting material but no further degradation or glycosidic bond cleavage were observed (Scheme 7).⁶⁴ The reduction of the sulfonyl moiety was not observed at this temperature. However, known fluorovinyl compound **21**⁶⁵ was obtained in 46% yield when **19** was treated with 3 eq. of **SED** at 120°C. This result indicated that reductive cleavage of the sulfone took place with excess **SED** at high temperature. Controlled-potential electrolysis of **19** in DMF at -1.90 V vs SCE, a potential more positive to the first potential peak measured by cyclic voltammetry (see Table S1), gave, after the consumption of 2.0 F/mole of substrate (1 h, r.t), a main fraction that contained **21** and **19** as an inseparable mixture (ratio ~ 8:2), with estimated yield of **21** close to 45% (Scheme 7). Noteworthy to mention that 2'-deoxy-2'-fluoridine **22**, the diacetylated **23** and uracil **12** (albeit in low amount) were also detected in the crude reaction mixture. These results were in line with the profile of products obtained with an excess of the **SED** reagent at 120°C/3h, however it offered an alternative milder approach to prepare **21** by a reductive approach. The results with **SED** or the electrochemical activation provided evidence that the C2' anion was indeed generated through C2'-S bond cleavage. It is important to note that replacement of **SED** with other reducing agents such as samarium iodide did not affect the reduction of the sulfonyl moiety.

Scheme 7. Reactivity studies of acetyl protected α -fluorosulfone **19** with OED and under electrochemical activation.

To avoid the elimination of the acetate anion from C3' position, the benzyl protected 2'- α -fluorosulfone derivative **24** was employed to study the reduction of the sulfone moiety with **SED**. However, treatment of **24** with **SED** under analogous conditions (3 equiv.; DMF, 120 °C, 3 h) produced a complex reaction mixture (Scheme 8), from which two major products were isolated: furan **25** and 3-*N*-benzyluracil **17**. Also observed by LC-MS was trace amounts of sulfone cleavage product **26**, providing

again evidence of the C2'-anion generation, trapped by proton abstraction. Intriguingly, in the furan derivative **25**, sulfone moiety was present and elimination of fluorine was observed. Furan derivative **25** could have been formed from either the reduction of the glycosidic bond followed by base induced fluoride elimination or *vice versa*. Analogous treatment of **24** with **SED** at room temperature gave only trace amounts of **25** and **17** along with unchanged starting material. Reaction in the presence of deoxygenated water at 80 °C, in order to favour the formation of reduction product **26** (to enhance proton abstraction), did not change the outcome of the reaction. The elimination product **25** and 3-*N*-benzyluracil **17** were obtained in 80% and 60% isolated yields respectively.

Scheme 8. Reactivity studies of benzyl protected α -fluorosulfone **24** with **SED** and under electrochemical activation.

Controlled-potential electrolysis of **24** in DMF at - 2.20 V vs SCE, a potential slightly less positive to the first peak potential measured by cyclic voltammetry (see Table S1), gave, after the consumption of 2.1 F/mole of substrate (1 h, r.t), **17** in 74% isolated yield and an inseparable mixture containing **24** and **26** (ratio ~ 2.5:1) with also additional products. The estimated yield of **26** was roughly 18%, a yield slightly higher compared to the reaction using the **SED** reagent (Scheme 8). Although the electrolysis did not go to complete conversion of starting material, as opposed to the results obtained with the **SED** reagent, there was no indication of formation of furan **25**. The electrochemical reductive cleavage of **24** seems to be more complex than **19** since generation of more products was observed, but formation of **22**, **23** and **26** under milder electrochemical conditions, is again an attractive starting point for further optimization studies and possible anion trapping.

Conclusion

In conclusion, new methods for the modification of nucleosides at the C2'-position *via* oxidative and reductive activation of carbon-sulfur bonds in readily available 2'-thionucleosides were studied. The

oxidative desulfurization-difluorination of aryl-alkyl thioethers including 2'-S-aryl-2'-thiouridine substrates, using the protocol of Haufe *et al.* was studied with mixed results. Although successful on 2-(arylthio)alkanoate surrogates, combination of oxidants and fluoride sources was not an efficient fluorination protocol when applied to 2'-thiouridine derivatives, resulting mainly in C5-halogenation of the pyrimidine ring and C2'-monofluorination without desulfurization. Our reductive desulfonylation approach using Organic Electron Donors (OEDs) was hampered by competitive base-induced mechanisms in the case of substrates bearing a labile α -hydrogen, resulting in the elimination of the uracil moieties. On the other hand, reduction of α -fluorosulfone derivatives with OED or by electrochemical activation provided good evidence that the C2'-anion was indeed generated through C2'-S bond cleavage. The major benefit of the electrochemical activation was the milder conditions of the protocol (r.t., no base, short time) leading to the formation of 2',3'-unsaturated-2'-fluorouridine and 2'-fluorinated products. These results open new horizons for the reductive desulfonylation-functionalization strategies, which, although, are still not fully developed in nucleosides, have the potential to be utilized in the synthesis of highly substituted nucleoside analogues including C2'-difluoro analogues.

Experimental Section

Reagent grade chemicals were used and solvents were dried by reflux and distillation from CaH₂ under N₂ unless otherwise specified, and an atmosphere of N₂ was used for reactions. The MBraun glovebox used for some reactions contained dry argon and less than 1 ppm oxygen and water. Reaction progress was monitored by TLC on Merck Kieselgel 60-F₂₅₄ sheets with product detection by 254-nm light. Products were purified by column chromatography using Merck Kieselgel 60 (230-400 mesh) or by automated flash chromatography using a CombiFlash system. UV spectra were recorded with a Varian Cary 100 Bio UV-visible spectrophotometer. ¹H (400 MHz), ¹³C (100.6 MHz), and ¹⁹F (376 MHz) NMR spectra were recorded at ambient temperature in solutions of CDCl₃ or DMSO-*d*₆. MS and HRMS spectra were recorded in ESI+ or ESI- mode, unless otherwise noted. The bispyridinylidene SED was synthesized following reported procedure,⁵⁸ stored in a glove box and used as a well-defined dark purple solid.

Electrochemical measurements were performed using an EG & G-Princeton Applied Research 263A all-in-one potentiostat, using a standard three-electrode setup with a glassy carbon electrode (working electrode, diameter = 3 mm), platinum wire auxiliary electrode and a non-aqueous Ag/Ag⁺ (0.01M AgNO₃ + 0.1M *n*-Bu₄NClO₄) system in MeCN as the reference electrode. All solutions under the study were 0.1 M in the supporting electrolyte *n*-Bu₄NPF₆ (Fluka, electrochemical grade) with the voltage scan rate of 0.2 V s⁻¹. Solutions (2.5 mL) were thoroughly bubbled with dry Ar for 15 min to remove oxygen before any experiment and kept under positive pressure of Ar. Under these experimental conditions the ferrocene/ferricinium couple, used as internal reference for potential measurements, was

located at $E_{1/2} = + 0.05$ V in DMF. Controlled-potential electrolyses were run in a cylindrical divided cell (see Figure S5) using a porous reticulated carbon electrode ($S \sim 2.5$ cm²) as working electrode, a platinum wire as counter electrode separated from the cathodic compartment with a frit glass (porosity 4) and Ag wire as pseudo reference. Cyclic voltammograms were recorded before the electrolysis and during the electrolysis using a glassy carbon electrode (diameter = 1 mm). The solutions containing the substrate and the supporting electrolyte (*n*-Et₄NBF₄ 0.1 M) were thoroughly bubbled with dry Ar for 15 min to remove oxygen before any experiment and kept under positive pressure of Ar.

Ethyl 2-(phenylthio)octanoate (2). Thiophenol (260 μ L, 280 mg, 2.54 mmol) was added to a stirred solution of NaH (60%, dispersion in paraffin liquid; 100.4 mg, 4.18 mmol) in anhydrous DMF (4 mL) at 0 °C. The resulting suspension was stirred at 0 °C for 30 min and at ambient temperature for 30 min, until bubbling (H₂ gas) ceased. The reaction flask was chilled again and ethyl 2-bromooctanoate (540 μ L, 630 mg, 2.51 mmol) was added at 0 °C. The resultant clear, colorless solution was stirred at 0 °C for 20 min and at ambient temperature for 2 h, by which time TLC showed exclusive conversion to a slightly more polar spot. Volatiles were evaporated and co-evaporated with toluene (1 x) (vacuum pump) and the resulting pale gum was partitioned between CHCl₃ (20 mL) and NH₄Cl/H₂O (20 mL). The aqueous layer was extracted with CHCl₃ (2 x 5 mL) and the combined organic phase was washed with NaHCO₃/H₂O (25 mL), brine (25 mL), and dried (MgSO₄). Volatiles were evaporated *in vacuo* and the residue was column chromatographed (10% EtOAc in hexanes) to give **2**⁶⁶ (633 mg, 90%) as a pale oil: ¹H NMR (CDCl₃) δ 7.49-7.46 (m, 2H, Ph), 7.35-7.25 (m, 3H, Ph), 4.16-4.09 (m, 2H, CH₂), 3.66 (dd, $J = 6.6, 8.4$ Hz, 1H, H₂), 1.96-1.87 (m, 1H, H₃), 1.82-1.73 (m, 1H, H_{3'}), 1.51-1.37 (m, 2H, H₄, H_{4'}), 1.36-1.26 (m, 6H, H₅, H_{5'}, H₆, H_{6'}, H₇, H_{7'}), 1.19 (t, $J = 7.1$ Hz, 3H, CH₃), 0.90 ("t", $J = 6.8$ Hz, 3H, CH₃); ¹³C NMR (CDCl₃) δ 172.4, 133.8, 132.7, 128.9, 127.7, 61.0, 50.9, 31.7, 31.5, 28.8, 27.2, 22.5, 14.1, 14.0.

Ethyl 2-((4-chlorophenyl)thio)hexanoate (3). Treatment of ethyl 2-bromohexanoate (500 μ L, 610.5 mg, 2.74 mmol) with 4-chlorothiophenol/NaH/DMF, as described for **2**, gave **3**⁶⁷ as a pale yellow oil (763.6 mg, 97%): ¹H NMR (CDCl₃) δ 7.41-7.37 (m, 2H, Ph), 7.30-7.26 (m, 2H, Ph), 4.17-4.09 (m, 2H, CH₂), 3.61 (dd, $J = 6.6, 8.4$ Hz, 1H, H₂), 1.94-1.84 (m, 1H, H₃), 1.81-1.69 (m, 1H, H_{3'}), 1.51-1.27 (m, 4H, H₄, H_{4'}, H₅, H_{5'}), 1.19 (t, $J = 7.1$ Hz, 3H, CH₃), 0.91 ("t", $J = 7.1$ Hz, 3H, CH₃); ¹³C NMR (CDCl₃) δ 172.1, 134.11, 134.10, 132.1, 129.0, 61.1, 51.0, 31.3, 29.4, 22.2, 14.1, 13.8.

Ethyl 2-((4-methoxyphenyl)thio)hexanoate (4). Treatment of ethyl 2-bromohexanoate (500 μ L, 610.5 mg, 2.74 mmol) with 4-methoxythiophenol/NaH/DMF, as described for **2**, gave **4**⁶⁸ as a colorless oil (739.3 mg, 96%): ¹H NMR (CDCl₃) δ 7.36-7.31 (m, 2H, Ph), 6.78-6.74 (m, 2H, Ph), 4.02 ("q", $J = 7.2$ Hz, 2H, CH₂), 3.41 (dd, $J = 6.6, 8.5$ Hz, 1H, H₂), 1.82-1.75 (m, 1H, H₃), 1.68-1.59 (m, 1H, H_{3'}), 1.42-

1.32 (m, 1H, H4), 1.30-1.21 (m, 3H, H4', H5, H5'), 1.10 (t, $J = 7.1$ Hz, 3H, CH₃), 0.82 (t, $J = 7.1$ Hz, 3H, CH₃); ¹³C NMR (CDCl₃) δ 172.2, 160.1, 136.2, 123.4, 114.4, 60.7, 55.2, 51.6, 31.1, 29.3, 22.3, 14.1, 13.8.

General procedure for the preparation of ethyl difluoroalkanoates (5). DBH (1.5 mmol) was added to a stirred solution of esters **2** or **3** or (0.5 mmol) and Py.9HF (3 mmol) in CH₂Cl₂ (2 mL) in a polypropylene vessel at ambient temperature. The resulting brown solution was stirred at 35 °C for 2 h (**2**), 1 h (**3**) or 16h (**4**). The reaction flask was cooled to room temperature, quenched by addition of ice-cold water, diluted with CH₂Cl₂, and neutralized with drop-wise addition of conc. NH₄OH. Organic layer was separated and aqueous layer was back extracted (2 x CH₂Cl₂). Combined organic layer was washed with 1N HCl, brine, dried (MgSO₄) and concentrated *in vacuo* to give crude difluorinated product **5b** (95% conversion from **2**) or **5a** (95% conversion from **3**; 70% conversion from **4**) as a brown oil, with data as reported.⁶⁹

5a⁶⁹ had: ¹H NMR (CDCl₃) δ 4.25 (q, ³ $J_{\text{H,H}} = 7.2$ Hz, 2H, CH₂), 2.09-1.88 (m, 2H, H3, H3'), 1.42-1.30 (m, 4H, H4, H4', H5, H5'), 1.28 (t, ³ $J_{\text{H,H}} = 7.1$ Hz, 3H, CH₃), 0.85 (t, ³ $J_{\text{H,H}} = 7.2$ Hz, 3H, H6, H6', H6''); ¹³C NMR (CDCl₃) δ 164.4 (t, ² $J_{\text{F,C}} = 33.2$ Hz, C1), 116.4 (t, ¹ $J_{\text{F,C}} = 249.8$ Hz, C2), 63.0 (CH₂), 34.5 (t, ² $J_{\text{F,C}} = 23.2$ Hz, C3), 23.5 (t, ³ $J_{\text{F,C}} = 4.3$ Hz, C4), 22.2 (C5), 13.9 (CH₃), 13.7 (C6); ¹⁹F NMR (CDCl₃) δ -105.92 ppm (t, ³ $J_{\text{F-H}} = 16.8$ Hz); GC-MS ($t_{\text{R}} = 7.5$ min) 151 (M⁺-Et, 1.1), 87 (100).

5b⁶⁹ had: ¹H NMR (CDCl₃) δ 4.25 (q, ³ $J_{\text{H,H}} = 7.2$ Hz, 2H, CH₂), 2.03-1.91 (m, 2H), 1.45-1.18 (m, 11H), 0.81 ("t", ³ $J_{\text{H,H}} = 6.8$ Hz, 3H, H6, H6', H6''); ¹³C NMR (CDCl₃) δ 164.5 (t, ² $J_{\text{F,C}} = 33.0$ Hz, C1), 116.4 (t, ¹ $J_{\text{F,C}} = 249.7$ Hz, C2), 62.7 (CH₂), 34.5 (t, ² $J_{\text{F,C}} = 23.2$ Hz, C3), 31.4, 28.7, 22.4, 21.4 (t, ³ $J_{\text{F,C}} = 4.3$ Hz, C4), 13.9; ¹⁹F NMR (CDCl₃) δ -105.89 ppm (t, ³ $J_{\text{F-H}} = 17.0$ Hz); GC-MS ($t_{\text{R}} = 7.4$ min) 179 (M⁺-Et, 60.8), 144 (100).

3-N-benzyl-3',5'-di-O-benzyl-5-iodo-2'-S-(4-methoxyphenyl)-2'-thiouridine(7) and **3-N-benzyl-3',5'-di-O-benzyl-2'-fluoro-2'-S-(4-methoxyphenyl)-2'-thiouridine(8)**. NIS (95 mg, 0.42 mmol) was added to a stirred solution of **6** (128 mg, 0.2 mmol) and Py.9HF (138 μ L, 0.6 mmol) in anhydrous CH₂Cl₂ (3 mL) at -78 °C in a polypropylene vessel and the resulting brown solution was brought to ~5 °C overnight (16 h). Stirring was continued at ambient temperature for 7 h (total reaction time: 23 h). The reaction was quenched by addition of ice-cold water (10 mL), diluted with CH₂Cl₂ (5 mL), neutralized with drop-wise addition of conc. NH₄OH. Organic layer was separated and aqueous layer was back extracted (2 x CH₂Cl₂). Combined organic layer was washed with 1N HCl (10 mL), brine (10 mL), dried (MgSO₄), and filtered. Volatiles were evaporated *in vacuo* and the brown residue was column chromatographed (5% → 20% EtOAc in hexanes) to give **7** (44 mg, 29%) as a colorless oil and **8**⁵¹ (2'-R/S-S, ~ 1:1; 16 mg, 12%) as a pale-yellow oil.

7 had: UV (MeOH) λ_{\max} 253, 283 nm, λ_{\min} 246, 273 nm; ^1H NMR (CDCl_3) δ 7.66-7.63 (m, 2H, Ph), 7.56 (s, 1H, H6), 7.44-7.31 (m, 13H, Ph), 7.12-7.10 (m, 2H, Ph), 6.51 (d, $J = 8.9$ Hz, 1H, H1'), 6.33-6.30 (m, 2H, Ph), 5.15 ("d", $J = 13.4$ Hz, 1H, benzylic), 5.02 ("d", $J = 13.3$ Hz, 1H, benzylic), 4.68-4.52 (m, 4H, benzylic), 4.33-4.25 (m, 2H, H4', H3'), 3.76-3.67 (m, 2H, H2', H5'), 3.66 (s, 3H, OCH_3), 3.51 (dd, $J = 2.0$, 10.5 Hz, 1H, H5"); ^{13}C NMR (CDCl_3) δ 159.8, 159.1, 150.8, 142.2 (C6), 137.22, 137.16, 136.2, 135.2, 130.4, 128.8, 128.6, 128.4, 128.2, 128.1, 128.06, 127.8, 127.7, 123.0, 114.7, 90.2 (C1'), 82.1 (C3'), 80.7 (C4'), 73.8 (CH_2), 72.3 (CH_2), 70.5 (C5), 68.9 (C5'), 56.4 (C2'), 55.5 (OCH_3), 46.0 (CH_2). HRMS (ESI) m/z 785.1119 [$\text{M}+\text{Na}$] $^+$, calcd for $\text{C}_{37}\text{H}_{35}\text{IN}_2\text{NaO}_6\text{S}^+$ 785.1133.

Analogous treatment of **6** (128 mg, 0.2 mmol) with NIS (95 mg, 0.42 mmol) and DAST (160 μL , 1.2 mmol) followed by aqueous workup (sat. $\text{Na}_2\text{S}_2\text{O}_3$, sat. NaHCO_3 , brine, MgSO_4) and column chromatography gave **8**⁵¹(2'-*R/S*-S, ~ 1:1; 58 mg, 44%) as a pale-yellow oil.

3-*N*-benzyl-3',5'-di-*O*-benzyl-5-bromo-2'-fluoro-2'-*S*-(4-methoxyphenyl)-2'-thiouridine(9).

Py.9HF (62 μL , 0.27 mmol) was added to a chilled solution of DBH (19 mg, 0.066 mmol) in dry CH_2Cl_2 (1 mL) at -78 °C. The resulting pale solution was stirred at -78 °C for 10 min and a solution of substrate **8** (40 mg, 0.06 mmol) in dry CH_2Cl_2 (2 mL) was added via syringe. The resultant orange solution was stirred at -78 °C for 2 h and was brought to -30 °C over 45 min. The reaction mixture was diluted with CH_2Cl_2 (5 mL), washed with $\text{NaHCO}_3/\text{H}_2\text{O}$ (5 mL), H_2O (5 mL), brine (5 mL), dried (MgSO_4). Volatiles were evaporated *in vacuo* and the yellow residue was column chromatographed (15% EtOAc in hexanes) to give **9** as mixture of diastereomers (2'-*R/S*-S, ~ 4:1) (pale-yellow oil, 22 mg, 50%): UV (MeOH) λ_{\max} 253, 280 nm, λ_{\min} 239, 271 nm; ^1H NMR (CDCl_3) δ 7.84 (s, 1H, H6), 7.81 (d, $J = 2.1$ Hz, 0.2H, Ph), 7.66 (d, $J = 2.2$ Hz, 0.8H, Ph), 7.49-7.23 (m, 17H, Ph), 6.78 (d, $J = 8.7$ Hz, 0.8H, Ph), 6.75 (d, $J = 8.7$ Hz, 0.2H, Ph), 6.44 (d, $J = 13.9$ Hz, 0.8H, H1'), 6.27 (br s, 0.2H, H1'), 5.09 ("d", $J = 13.6$ Hz, 1H, benzylic), 4.92-4.80 (m, 1H, benzylic), 4.73-4.65 (m, 1H, benzylic), 4.62-4.41 (m, 3H, benzylic), 4.18-4.09 (m, 2H, H3', H4'), 3.92 (s, 0.6H, CH_3), 3.91 (s, 2.4H, CH_3), 3.82-3.72 (m, 1H, H5'), 3.61-3.53 (m, 1H, H5"); ^{19}F NMR (CDCl_3) δ -133.52 ppm (br s, 0.8F), -131.57 ppm (br s, 0.2F); ^{13}C NMR (CDCl_3) for major isomer: δ 158.4, 157.2, 149.4, 138.1, 137.79, 137.76, 137.3, 136.8, 135.9, 134.1, 134.0, 129.3, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 128.0, 127.9, 120.24, 120.23, 112.2, 112.0, 108.7 (d, $^1J_{\text{C}2-\text{F}} = 239.1$ Hz, C2'), 96.9, 90.4 (d, $^2J_{\text{C}1-\text{F}} = 47.3$ Hz, C1'), 80.3 (C4'), 79.7 (d, $^2J_{\text{C}3-\text{F}} = 17.7$ Hz, C3'), 73.5 (CH_2), 73.1 (CH_2), 67.0 (C5'), 56.4 (OCH_3), 45.7 (CH_2). HRMS (ESI) m/z 755.1182 [$\text{M}+\text{Na}$] $^+$, calcd for $\text{C}_{37}\text{H}_{34}^{79}\text{BrFN}_2\text{NaO}_6\text{S}^+$ 755.1197.

5'-*O*-Acetyl-2',3'-dideoxy-2',3'-didehydro-2'-[(4-methoxyphenyl)sulfonyl]uridine (13), 1-[5-acetyl-4-hydroxy-2-((4-methoxyphenyl)sulfonyl)-1,3-pentadien-1-yl]uracil(14) and **[4-[(4-methoxyphenyl)sulfonyl]furan-2-yl]methyl acetate (11)**. TDAE (0.24 mL, 1.04 mmol) was added to a

stirred solution of **10** (100 mg, 0.207 mmol) in anhydrous DMF (2 mL) at -78 °C under argon. The reaction mixture was brought to ambient temperature over 1h 15 min and a 10% HCl solution (2 mL) was then added. The crude was extracted with EtOAc (3 x) and the combined organic phase was dried over anhydrous Na₂SO₄. Volatiles were evaporated *in vacuo* and the residue was column chromatographed (PE 100% → EtOAc/PE 2/1 → EtOAc 100%) to give **11** (29.5 mg, 46%), **14** (17.5 mg, 20%), and **13** (30 mg, 34%), all as colorless oils.

13 had: ¹H NMR (CDCl₃) δ 9.23 (br, 1H, NH), 7.79-7.75 (m, 2H, Ph), 7.24 (d, *J* = 8.4 Hz, 1H, H₆), 7.18 (t, *J* = 1.6 Hz, 1H, H_{3'}), 7.03-6.99 (m, 3H, Ph, H_{1'}), 5.55 (dd, *J* = 2, 8.4 Hz, 1H, H₅), 5.12-5.09 (m, 1H, H_{4'}), 4.41 (dd, *J* = 4, 12.4 Hz, 1H, H_{5'}), 4.29 (dd, *J* = 3.6, 12.4 Hz, 1H, H_{5''}), 3.87 (s, 3H, OCH₃), 2.09 (s, 3H, Ac); ¹³C NMR (50 MHz, CDCl₃) δ 170.1 (C=O), 164.9 (C^{Ph}), 162.9 (C₄), 150.3 (C₂), 142.1 (C₆), 141.9 (C_{2'}), 139.5 (C_{3'}), 130.8 (CH^{Ph}), 129.1 (C^{Ph}), 115.2 (CH^{Ph}), 103.2 (C₅), 87.5 (C_{1'}), 82.8 (C_{4'}), 63.9 (C_{5'}), 56.1 (OCH₃), 20.8 (Ac). HRMS (ESI) *m/z* 423.0856 [M+H]⁺, calcd for C₁₈H₁₉N₂O₈S⁺ 423.0857.

14 had: ¹H NMR (CDCl₃) δ 9.00 (br s, 1H, NH), 7.76 (d, *J* = 8.8 Hz, 2H, Ph), 7.58 (s, 1H, H_{1'}), 6.97-6.99 (m, 3H, Ph, H₆), 5.69 (br, 1H, OH), 5.62 (dd, *J* = 1.2, 8.0 Hz, 1H, H₅), 4.93-4.79 (m, 1H, H_{3'}), 4.27 (dd, *J* = 4.4, 12.4 Hz, 1H, H_{5'}), 4.21 (dd, *J* = 4.8, 12.4 Hz, 1H, H_{5''}), 3.86 (s, 3H, OCH₃), 1.95 (s, 3H, Ac); ¹³C NMR (CDCl₃) δ 170.4 (C=O), 164.2 (C^{Ph}), 162.6 (C₄), 160.3 (C_{1'}), 150.3 (C₂), 140.2 (broad, C₆), 131.5 (C^{Ph}), 129.9 (CH^{Ph}), 116.9 (broad, C_{2'}), 114.9 (CH^{Ph}), 103.7 (C₅), 88.7 (broad, C_{3'}), 63.4 (C_{5'}), 55.6 (OCH₃), 20.5 (CH₃^{Ac}). HRMS (ESI) *m/z* 423.0864 [M+H]⁺, calcd for C₁₈H₁₉N₂O₈S⁺ 423.0857; 440.1119 [M+NH₄]⁺, calcd for C₁₈H₂₂N₃O₈S⁺ 440.1122.

11 had: ¹H NMR (CDCl₃) δ 7.93 (d, *J* = 0.8 Hz, 1H, H₁), 7.85-7.89 (m, 2H, Ph), 6.96-7.00 (m, 2H, Ph), 6.56 (s, 1H, H₃), 4.97 (s, 2H, H₅, H_{5'}), 3.85 (s, 3H, OCH₃), 2.05 (s, 3H, Ac); ¹³C NMR (CDCl₃) δ 170.3 (C=O), 163.8 (C^{Ph}), 152.4 (C₄), 145.7 (C₁), 132.9 (C₂), 131.1 (C^{Ph}), 129.8 (CH^{Ph}), 114.7 (CH^{Ph}), 108.7 (C₃), 57.4 (C₅), 55.8 (OCH₃), 20.8 (CH₃^{Ac}); HRMS (ESI) *m/z* 328.0852 [M+NH₄]⁺, calcd for C₁₄H₁₈NO₆S⁺ 328.0849.

[4-[(4-Methoxyphenyl)sulfonyl]furan-2-yl]methyl acetate (11) and **uracil (12)**. In a glove box, **SED** (31 mg, 0.1 mmol) was added to a solution of **10** (50 mg, 0.1 mmol) in anhydrous DMF (4 mL) and the resulting mixture was stirred at ambient temperature for 15 min. Then the reaction flask was brought out of the glove box and water was added to the crude reaction mixture. The aqueous phase was extracted with CH₂Cl₂ (3 x), the combined organic phase was dried over anhydrous Na₂SO₄ and volatiles were evaporated *in vacuo* to give **11** (29.4 mg, 95%) as a colorless oil.

Acidification of the aqueous phase (pH ~5-6) followed by extraction (2 x CH₂Cl₂) gave a white solid. ¹H NMR (MeOD) of the white solid revealed the presence of uracil **12** along with other impurities.

3,5-di-O-Benzyl-1,2-dideoxy-1,2-didehydro-2-[(4-methoxyphenyl)sulfonyl]ribose (16), **2-[(benzyloxy)methyl]-4-[(4-methoxyphenyl)sulfonyl]furan (18)** and **3-N-benzyluracil (17)**. In a glove

box, **SED** (22 mg, 7×10^{-5} mol, 1.05 equiv.) was added to a solution of **15** (45 mg, 6.7×10^{-5} mol) in DMF (4 mL) and the reaction mixture was stirred at ambient temperature for 15 min. Then the reaction flask was brought out of the glove box and water was added to the crude reaction mixture. The aqueous phase was extracted with CH_2Cl_2 (3 x) and the combined organic phase was dried over anhydrous Na_2SO_4 . Volatiles were evaporated *in vacuo* and the residue was column chromatographed (PE 100% \rightarrow PE/EtOAc 9/1 \rightarrow EtOAc 100%) to give **16** (22 mg, 70%) as a white gum and **17** (9.4 mg, 69%) as a white solid.

16 had: ^1H NMR (CDCl_3) δ 7.83-7.79 (m, 2H, Ph), 7.42 (s, 1H, H1), 7.37-7.31 (m, 3H, Ph), 7.26-7.24 (m, 5H, Ph), 7.09-7.07 (m, 2H, Ph), 6.86-6.84 (m, 2H, Ph), 4.86 (d, $J = 3.2$ Hz, 1H, H3), 4.77 (td, $J = 3.2, 5.6$ Hz, 1H, H4), 4.49 (d, $J = 2.4$ Hz, 2H, CH_2), 4.40 (s, 2H, CH_2), 3.81 (s, 3H, OCH_3), 3.48 (dd, $J = 5.6, 10.4$ Hz, 1H, H5), 3.40 (dd, $J = 5.6, 10.4$ Hz, 1H, H5); ^{13}C NMR (CDCl_3) δ 163.3 (C^{Ph}), 159.7 (C1), 137.4 (C^{Ph}), 137.3 (C^{Ph}), 133.6 (C^{Ph}), 129.8 (2 CH^{Ph}), 128.7 (2 CH^{Ph}), 128.4 (2 CH^{Ph}), 128.1 (3 CH^{Ph}), 128.0 (CH^{Ph}), 127.9 (2 CH^{Ph}), 119.7 (C2), 114.2 (2 CH^{Ph}), 90.3 (C3), 80.7 (C4), 73.7 (CH_2), 70.8 (CH_2), 68.9 (C5), 55.7 (OCH_3); HRMS (ESI) m/z 484.1789 [$\text{M} + \text{NH}_4$] $^+$, calcd for $\text{C}_{26}\text{H}_{30}\text{NO}_6\text{S}^+$ 484.1788.

Analogous treatment of **15** (50 mg, 7.5×10^{-5} mol) with **SED** (64 mg, 2.2×10^{-4} mol, 3 equiv.) in DMF (4 mL) for 30 min at room temperature gave **18** as a mixture with **16** (colorless oil; 7.4 mg; ratio of **16**:**18** is 33/67) and **17** (13 mg, 86%) as a white solid.

18 had: ^1H NMR (200 MHz, CDCl_3) δ 7.93 (s, 1H, H1), 7.91-7.84 (m, 2H, Ph), 7.36-7.30 (m, 5H, Ph), 7.01-6.96 (m, 2H, Ph), 6.49 (s, 1H, H3), 4.53 (s, 2H, CH_2), 4.42 (s, 2H, H5), 3.86 (s, 3H, OCH_3); MS (ESI) m/z 376.17 [$\text{M} + \text{NH}_4$] $^+$, calcd for $\text{C}_{19}\text{H}_{22}\text{NO}_5\text{S}^+$ 376.12.

5'-O-Acetyl-2',3'-didehydro-2',3'-dideoxy-2'-fluorouridine (21). In a glove box, **SED** (68 mg, 0.24 mmol, 3 equiv.) was added to a stirred solution of **19** (40 mg, 0.08 mmol) in anhydrous DMF (4 mL) and the resulting dark brown solution was stirred at 120 $^\circ\text{C}$ for 18 h. Reaction flask was brought out of the glove box, and 10% HCl solution was added to the crude reaction mixture. Aqueous layer was extracted with CH_2Cl_2 (2 x). Combined organic layer was dried (Na_2SO_4), filtered, and concentrated *in vacuo* to give a brown solid. Et_2O was added to the solid and was filtered. Filtrate was concentrated *in vacuo* to give **21** (<10 mg, ~46%) along with other impurities. ^1H NMR of the black solid ($\text{DMSO}-d_6$) showed similar peaks to the ones obtained for the oxidized form of the **SED** (**SED** $^{2+}$).⁵⁸

21⁶⁵ had: ^1H NMR (CDCl_3) δ 8.47 (br s, 1H, NH), 7.52 (dd, $J = 1.0, 8.1$ Hz, 1H, H6), 6.90-6.88 (m, 1H, H1'), 5.78 (d, $J = 8.1$ Hz, 1H, H5), 5.69 (m, 1H, H3'), 5.06-5.02 (m, 1H, H4'), 4.35-4.21 (m, 2H, H5', 5''), 2.11 (s, 3H, Ac); ^{19}F NMR (CDCl_3) δ -133.76 (t, $J = 4.6$ Hz, F2'); MS (EI) m/z 271.09 [$\text{M} + \text{H}$] $^+$, calcd for $\text{C}_{11}\text{H}_{12}\text{FN}_2\text{O}_5^+$ 271.07.

3-(Benzyloxy)-2-[(benzyloxy)methyl]-4-[(4-methoxyphenyl)sulfonyl]furan (25). In a glove box, **SED** (62 mg, 0.22 mmol, 3 equiv.) was added to a solution of **24** (50 mg, 7.3×10^{-5} mol) in anhydrous

DMF (4 mL) and the resulting solution was stirred at 120 °C for 3 h. Reaction flask was brought out of the glove box, and water was added to the crude reaction mixture. The aqueous phase was extracted with CH₂Cl₂ (3 x) and the combined organic phase was dried with Na₂SO₄. Volatiles were evaporated *in vacuo* and the residue was column chromatographed (PE/EtOAc 9/1 → EtOAc 100%) to give **25** (19.6 mg, 58%) as a white gum and 3-*N*-benzyluracil (**17**; 12.4 mg, 84%) as white solid.

Analogous treatment, in a glove box, of **24** (58.3 mg, 8.5 x 10⁻⁵ mol) with **SED** (72 mg, 0.25 mmol, 3 equiv.) at ambient temperature for 4 h showed only trace amounts of **25** and **17** on TLC. Addition of degassed water (0.5 mL, 500 mg, 27.75 mmol) followed by heating at 80 °C for 30 min gave, after workup and silica gel chromatography, **25** (31.7 mg, 80%) and **17** (10.1 mg, 60%).

25 had: ¹H NMR (200 MHz, CDCl₃) δ 7.94-7.87 (m, 2H, Ph), 7.83 (s, 1H, H1), 7.37-7.24 (m, 10H, Ph), 6.95-6.88 (m, 2H, Ph), 5.07 (s, 2H, CH₂), 4.41 (s, 2H, CH₂), 4.17 (s, 2H, CH₂), 3.84 (s, 3H, OCH₃); ¹³C NMR (50 MHz, CDCl₃) δ 163.6 (C3), 144.8 (C1), 142.4 (C^{Ph}), 140.7 (C^{Ph}), 137.4 (C^{Ph}), 136.2 (C^{Ph}), 132.8 (C4), 130.0 (CH^{Ph}), 128.55 (CH^{Ph}), 128.53 (CH^{Ph}), 128.48 (CH^{Ph}), 128.0 (CH^{Ph}), 127.9 (CH^{Ph}), 125.6 (C2), 114.3 (CH^{Ph}), 77.3 (CH₂), 72.4 (CH₂), 61.1 (CH₂), 55.7 (OCH₃). HRMS (ESI) *m/z* 482.1632 [M+NH₄]⁺, calcd for C₂₆H₂₈NO₆S⁺ 482.1632.

General procedure for the electrolysis of 19 and 24. Under argon was introduced in the cathodic compartment, 10 mL of an anhydrous DMF solution containing *n*-Et₄NBF₄ 0.1 M and 2.5 mL of the same solution in the anodic compartment (see Figure S6 for the cell). The cathodic solution was deoxygenated with argon bubbling for 15 min and then were introduced **19** or **24**. Solution was stirred and deoxygenated further for 10 min. A cyclic voltamogram was then recorded using a glassy carbon electrode in order to determine the reduction potential of starting material. A constant potential of - 2.21 V for **19** or - 2.51 V for **24** was then applied at room temperature, with an initial current close to 12-18 mA. The progress of the electrolysis was followed by cyclic voltammetry. After 2.0-2.1 F/mole of starting material (1 h), the electrolysis was stopped and quenched with an aqueous NH₄Cl solution and extracted with EtOAc (3 x), the combined organic phase were washed with H₂O (3 x), dried over Na₂SO₄ and filtered. Concentration *under vacuo* left a residue that was purified by silica gel chromatography.

From 0.09 g (0.180 mmol) of **19**, 75.1 mg of a viscous yellow oil was obtained as a crude product. Column chromatography (5% MeOH in CHCl₃) gave a fraction (31.2 mg) that contained an inseparable mixture of **21** and **19** (ratio 8:2) with estimated yields of **21** (45%) and **19** (6%) from ¹H- and ¹⁹F-NMR. Further elution gave traces amount of **22**, **23** along with other fluorinated impurities as confirmed by mass spectrometry and NMR.

From 0.09 g (0.131 mmol) of **24**, 89.6 mg of a viscous yellow oil was obtained as crude product. Column chromatography (5% MeOH in CHCl₃) gave a fraction (50 mg) that contained an inseparable mixture of **24** and **26** and (ratio ~ 2.5:1) with estimated yields of **24** (43%) and **26** (18%) from ¹H- and ¹⁹F-

NMR. Further elution gave **17** (74%) in addition to other fluorinated impurities.

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Table of Contents Graphic

Text for TOC

New strategies for the modification of nucleosides at the C2'-position *via* oxidative and reductive activation of carbon-sulfur bonds in readily available 2'-thionucleosides were studied. Oxidative fluorination of **A** gave α -fluorothioether **B**. Reductive desulfonylation of α -fluorosulfone **E** yielded fluoro nucleosides **D** and/or **C** providing evidence of the generation of a C2'-anion through carbon-sulfur bond cleavage.