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A General Strategy for the Stereoselective Synthesis of Pyrrole-Fused Chiral Skeletons: [3+2] Cycloaddition with 2-Nitro-2,3-Unsaturated Glycosides

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In this study, a two-step methodology was developed for the synthesis of chiral pyrroles from 2-nitroglycals *via* Ferrier rearrangement and Barton-Zard reaction under mild conditions without transition metal catalysts. The Ferrier rearrangement reaction of 2-nitro-glycals and a series of *O*-nucleophiles proceeded smoothly in the presence of *N*-heterocyclic carbene (NHC) catalyst and K_2CO_3 which allowed the highly stereoselective synthesis of the diverse 2-nitro-2,3-unsaturated glycosides in excellent yields. Subsequently, the rearrangement products were conveniently transformed into the desired chiral pyrroles by [3+2] cycloaddition (Barton-Zard reaction) with isocyanoacetate in the presence of Cs_2CO_3. One-pot strategy was also successfully demonstrated for the gram-scale synthesis of one chiral pyrrole. This is the first report of stereoselective conversion from 2-nitroglycals to chiral pyrrole.

Introduction

As a molecular recognition motif, pyrrole is present in many complex natural products, artificial anion receptors and drugs, including chlorophyll, porphyrins, antitumor Spiroindimicin B, Pyrotinib and antiviral Galidesivir (Figure 1).[1] In the pyrrole family, polysubstituted chiral pyrroles, which constitute an important family of five-membered *N*-containing heterocycles with diverse biological properties and synthetic applications, have gained increasing attention of the organic and medicinal chemists.[2] For instance, Phaeosphaeride A and B, which contain the structural unit of chiral-substituted pyrrole, have been extensively studied due to their antitumor activity and ability to inhibit STAT3 signal transduction pathway.[3] As a result, significant research efforts have been devoted to achieving the practical, atom- and step-economic synthesis of chiral pyrrole compounds, with the synthetic methods constantly being innovated and improved.[4]

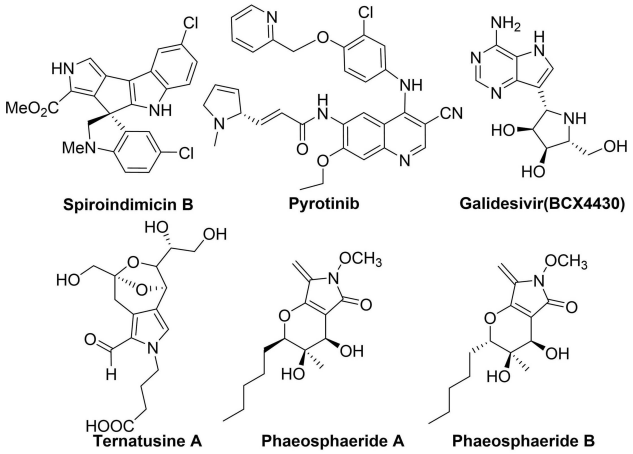

Figure 1. Bioactive natural products containing a pyrrolic ring.

There are usually two types of strategies for the synthesis of chiral pyrroles. In the first method, chiral pyrroles are synthesized from achiral raw materials (Scheme 1a). However, this method is usually limited by the expensive chiral catalysts and starting materials, along with harsh conditions. The other method is based on the use of chiral materials, such as alkaloids, sterols, saccharides, tartaric acid, *etc.*, which can be easily obtained from nature. Among these, saccharides have attracted widespread attention and been extensively studied[5] due to their abundant sources, low cost, mild reaction conditions and diverse chirality.[6] Therefore, the development of new synthetic reagents and novel strategies to synthesize substituted pyrroles from saccharides using mild conditions is of vital importance.

The reactions involving the [3+2] cycloaddition of unsaturated compounds and isocyanoacetate are among the most effective methods for accessing a pyrrole skeleton.[7] For instance, Zhao *et al.* developed a mild cycloaddition reaction of allenoic acid ester and methyl isocyanoacetate catalyzed by PPh_3 (Scheme 1b).[8] In another study, Zhang *et al.* reported the reaction with trifluoromethyl ketene, thereby achieving trifluoromethyl substituted chiral pyrrolidine derivatives with high yields and stereoselectivity (Scheme 1c).[9] However, only a few methods have been developed to date for the synthesis of

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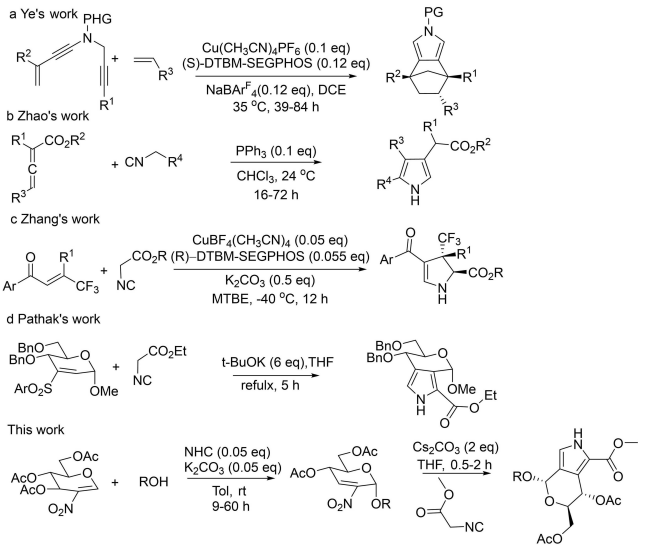


Scheme 1. Methods of Synthesizing Chiral Pyrrole and This Work.

chiral pyrrole from saccharide skeleton.[1] In 2009, Pathak *et al.* reported the synthesis of polysubstituted chiral pyrroles from vinyl sulfone-modified 2,3-unsaturated glycosides (Scheme 1d).[10] However, due to the harsh reaction conditions, the substrate scope is limited to only 12 examples. To extend the reaction generality and applicability, it is envisaged that the NO_2 substitution in the 2,3-unsaturated glycosides would reduce the electronic density of the double bond, which might accelerate the process of the proposed [3 + 2] cycloaddition, therefore, making the reaction more convenient and amiable, as a typical Barton-Zard reaction.[11]

In recent years, many efforts have been made for the synthesis of 2,3-unsaturated glycosides, which are important precursors for organic synthesis.[12] The Ferrier rearrangement of glycals is the most common methodology to obtain these glycosides.[13] However, only a few studies have reported the synthesis of 2-nitro-2,3-unsaturated glycosides[14] from 2-nitroglycal.[15] Vankar *et al.* synthesized 2-nitro-2,3-unsaturated glycosides by using DMAP as an effective catalyst, and provided 10 substrates. Thus, efforts are still needed to develop a general methodology that can provide a direct and rapid access to 2-nitro-2,3-unsaturated glycosides.

In previous studies, the substituent, sugar type and reaction conditions have been observed to have a significant influence on the reaction with glycals, even with the same catalyst.[16–19] Chen *et al.* recently reported an efficient stereoselective addition of perbenzylated 2-nitrogalactals with alcohols catalyzed by *N*-heterocyclic carbene (NHC).[20] In order to achieve the Ferrier rearrangement of 2-nitroglycal, we envisage that the introduction of acetyl substitution in glycals would accelerate the proposed Ferrier rearrangement. Thus, based on NHC catalysis, an efficient method for the synthesis of 2-nitro-2,3-unsaturated glycoside from 2-nitroglycals has been developed. To the best of our knowledge, this is the first report of NHC-catalyzed Ferrier rearrangement.

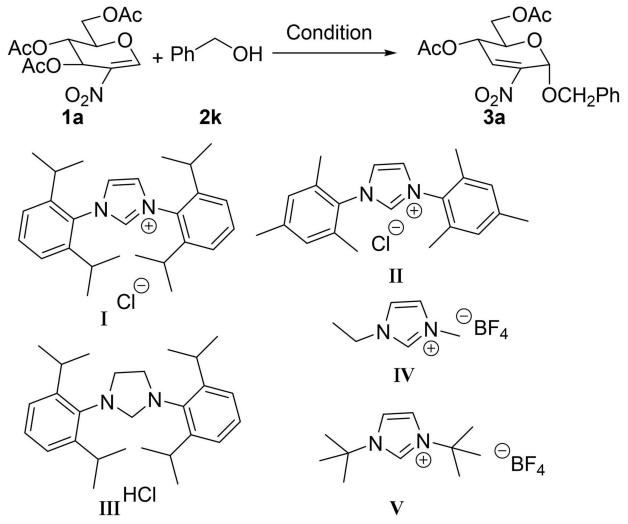
Results and Discussion

In the initial experiments, the screening of a series of commercial NHC catalysts was carried out (I–V in Table 1 10 mol%) to ascertain their ability to promote the glycosylation of tri-*O*-acetylated 2-nitroglycal 1a with benzyl alcohol **2a**. All NHC catalysts were observed to activate the glycal molecules, and **3a** was obtained in good yields (51–76%), with NHC (I) exhibiting the optimal result. It implied that the steric bulk in NHC catalysts plays an important role during the reaction. A series of bases were also screened for the glycosylation reaction in the presence of NHC (I). An optimal alkalinity is critical for the glycosylation reaction. K_2CO_3 revealed an effective activation of NHC, while avoiding the decomposition of glycals and products. Besides, toluene as solvent and room temperature conditions observed to be suitable. Also, reducing the equivalent of NHC (I) and K_2CO_3 to 0.05 is beneficial to the reaction. The donor to acceptor ratio of 1:2 was employed during the reaction. Finally, we performed conditional control experiments (Entries 30 and 31). We found that when there was only K_2CO_3 in the system without NHC, the corresponding **5a** compound was obtained at a yield of 61% with $\alpha{:}\beta = 3.4{:}1$, indicating that NHC plays an important role in controlling the stereoselectivity of the product in this reaction. When NHC (I) was used as catalyst only, the reaction did not proceed.

After determining the optimal reaction conditions for the Ferrier rearrangement, the optimal conditions for the [3 + 2] cycloaddition with methyl isocyanoacetate **4** and **3a** as the template substrates were explored (Table 2). First, different bases were screened, and the use of weak bases such as Na_2CO_3 and K_2CO_3 did not lead to a smooth reaction. On the other hand, the use of strong bases such as KOH, NaOH and *t*-BuOK promoted the reaction, and **5a** was successfully obtained as the major product in good to excellent yields (68–83%). However, the formation of by-products was enhanced accordingly due to high alkalinity. The outcome of the experiment suggested that **3a** tended to undergo [3 + 2] cycloaddition to provide **5a** under the catalytic action of an appropriate base (such as Cs_2CO_3). The organic bases such as DBU successfully promoted the reaction, however, the yield was inferior as compared to Cs_2CO_3. Using nucleophilic bases such as DMAP and DABCO, the system rapidly became complex, and the product **5a** was not detected. The base survey revealed 2 equivalents of Cs_2CO_3 as the preferred choice in terms of yield. Subsequently, different solvents and reaction temperatures were explored. Based on the earlier optimized conditions, THF as solvent and room temperature were observed to be suitable. Besides, the donor to acceptor ratio of 1:1.2 was observed to be optimal.

After determining the reaction conditions, the substrate scope for the glycosylation reaction with different nucleophiles was subsequently explored. As shown in Table 3, for benzyl alcohol or benzyl alcohol containing substituents, the reaction proceeded smoothly, and the products **3a**–**3d** were obtained

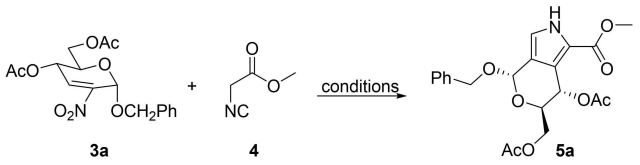
Table 1. Optimization of the Ferrier rearrangement reaction conditions.[a]



Entry	Cat. (equiv.)	Base (equiv.)	Solvent	T/ °C	Ratio (**1**:**2**)	Yield(%)[b]
1	**I** (0.1)	Cs_2CO_3 (0.1)	DCM	rt	1:2	76
2	**II** (0.1)	Cs_2CO_3 (0.1)	DCM	rt	1:2	72
3	**III** (0.1)	Cs_2CO_3 (0.1)	DCM	rt	1:2	51
4	**IV** (0.1)	Cs_2CO_3 (0.1)	DCM	rt	1:2	54
5	**V** (0.1)	Cs_2CO_3 (0.1)	DCM	rt	1:2	56
6	**I** (0.1)	Li_2CO_3 (0.1)	DCM	rt	1:2	trace
7	**I** (0.1)	Na_2CO_3 (0.1)	DCM	rt	1:2	72
8	**I** (0.1)	KOH (0.1)	DCM	rt	1:2	73
9	**I** (0.1)	NaOH (0.1)	DCM	rt	1:2	70
10	**I** (0.1)	DBU (0.1)	DCM	rt	1:2	34
11	**I** (0.1)	*t*-BuOK (0.1)	DCM	rt	1:2	41
12	**I** (0.1)	K_2CO_3 (0.1)	DCM	rt	1:2	78
13	**I** (0.1)	K_2CO_3 (0.1)	Tol	rt	1:2	82
14	**I** (0.1)	K_2CO_3 (0.1)	DCE	rt	1:2	76
15	**I** (0.1)	K_2CO_3 (0.1)	THF	rt	1:2	52
16	**I** (0.1)	K_2CO_3 (0.1)	MeCN	rt	1:2	47
17	**I** (0.1)	K_2CO_3 (0.1)	DMF	rt	1:2	trace
18	**I** (0.1)	K_2CO_3 (0.1)	1,4-dioxane	rt	1:2	45
19	**I** (0.2)	K_2CO_3 (0.2)	Tol	rt	1:2	78
20	**I** (0.3)	K_2CO_3 (0.3)	Tol	rt	1:2	70
21	**I** (0.05)	K_2CO_3 (0.05)	Tol	rt	1:2	85
22	**I** (0.05)	K_2CO_3 (0.05)	Tol	0	1:2	72
23	**I** (0.05)	K_2CO_3 (0.05)	Tol	40	1:2	71
24	**I** (0.05)	K_2CO_3 (0.05)	Tol	60	1:2	63
25	**I** (0.05)	K_2CO_3 (0.05)	Tol	80	1:2	50
26	**I** (0.05)	K_2CO_3 (0.05)	Tol	rt	1:1.2	64
27	**I** (0.05)	K_2CO_3 (0.05)	Tol	rt	1:1.5	78
28	**I** (0.05)	K_2CO_3 (0.05)	Tol	rt	1:3	84
29	**I** (0.05)	K_2CO_3 (0.05)	Tol	rt	1:4	83
30	-	K_2CO_3 (0.05)	Tol	rt	1:2	61
31	**I** (0.05)	-	Tol	rt	1:2	n.d.[c]

[a] The reaction was conducted with **1a** (0.2 mmol, 1 equiv.). using 2 mL solvent; [b] Isolated yield; [c] n.d. = not determined.

Table 2. Optimization of the [3 + 2] cycloaddition reaction conditions.[a]

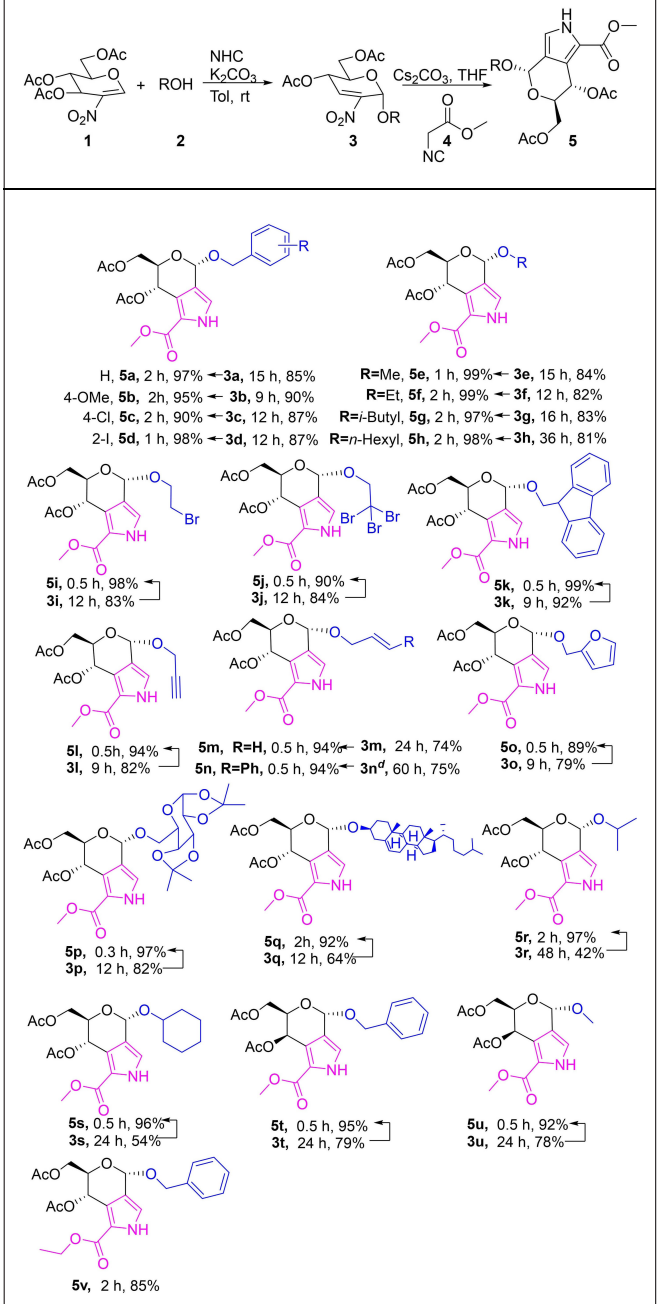


Entry	Cat.	Solvent	T/ °C	Ratio(**3**:**4**)	Yield(%)[b]
1	K_2CO_3(2)	DCM	rt	1:1.2	trace
2	Na_2CO_3(2)	DCM	rt	1:1.2	trace
3	Cs_2CO_3(2)	DCM	rt	1:1.2	93
4	KOH(2)	DCM	rt	1:1.2	68
5	NaOH(2)	DCM	rt	1:1.2	70
6	*t*-BuOK(2)	DCM	rt	1:1.2	83
7	DBU(2)	DCM	rt	1:1.2	89
8	DMAP(2)	DCM	rt	1:1.2	n.d.[c]
9	DABCO(2)	DCM	rt	1:1.2	n.d.[c]
10	Cs_2CO_3(1)	DCM	rt	1:1.2	63
11	Cs_2CO_3(1.5)	DCM	rt	1:1.2	88
12	Cs_2CO_3(2.5)	DCM	rt	1:1.2	86
13	Cs_2CO_3(3)	DCM	rt	1:1.2	90
14	Cs_2CO_3(2)	DCE	rt	1:1.2	89
15	Cs_2CO_3(2)	Tol	rt	1:1.2	92
16	Cs_2CO_3(2)	1,4-dioxane	rt	1:1.2	78
17	Cs_2CO_3(2)	MeCN	rt	1:1.2	31
18	Cs_2CO_3(2)	DMF	rt	1:1.2	10
19	Cs_2CO_3(2)	THF	rt	1:1.2	97
20	Cs_2CO_3(2)	THF	rt	1:1	95
21	Cs_2CO_3(2)	THF	rt	1:1.5	97
22	Cs_2CO_3(2)	THF	rt	1:2	97
23	Cs_2CO_3(2)	THF	0	1:2	81
24	Cs_2CO_3(2)	THF	40	1:2	75
25	Cs_2CO_3(2)	THF	60	1:2	52

[a] The reaction was conducted with **3** (0.1 mmol, 1 equiv.), using 1 mL solvent; [b] Isolated yield; [c] n.d. = not detected.

with excellent yields. The simple alcohols (**2e**–**2h**) were suitable for the reaction, and the rearrangement products were obtained with yields of 81–84%. Notably, the substrates bearing halogen functionalities **3e**–**3f** underwent the desired transformation without any elimination side reactions, thus, offering opportunities for further synthetic transformations. For fluorene methanol **2k**, the corresponding rearrangement product **3k** was obtained with excellent yield. Besides, the reaction tolerated alcohols containing double or triple bonds, such as propargyl alcohol and allyl alcohol, with the corresponding products **3l**–**3m** obtained in high yields. Reducing the temperature was beneficial to enhance the yield of **3n**. The heteroaromatic compound was compatible with the transformation process, thus, affording the desired **3o** in 79% yield. Moreover, the glycosyl acceptor **2p** also was applied to the system, and the corresponding disaccharide **3p** was obtained. The reaction was also noted to be applicable to cholesterol with complex structure. For a few secondary alcohols, such as isopropanol and cyclohexanol, the yields of **3r** and **3s** were observed to decline. The reaction proceeded smoothly for galactose donors **3t**–**3u**. Subsequently, **3a**–**3u** were successfully converted to

Table 3. Scope of substrate.[a,b,c]



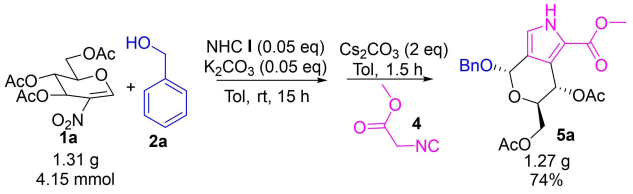
[a] The reaction was conducted with 1 equiv. (0.2 mmol) of **1a** and 2 equiv. (0.4 mmol) of **2a**. The [3+2] cycloaddition reaction was conducted with 1 equiv. (0.1 mmol) of **3a** and 1.2 equiv. (1.2 mmol) of **4**; [b] Isolated yield; [c] Diastereoselective (α:β) ratio determined by ^{1}H NMR analysis; [d] The reaction was conducted at 0 °C.

the desired [3+2] cycloaddition products **5a–5u** with high yields (up to 99%). Moreover, ethyl isocyanoacetate was proven as an effective substrate in Barton-Zard reaction to give another [3+2] cycloaddition product 5v. The structure and stereochemistry of the rearrangement and cycloaddition products were elucidated by NMR and mass spectroscopy and were subsequently compared with the reported data.[14] The stereoselectivity of **3a–3u** and **5a–5u** were confirmed by NMR spectroscopy to be very high (α:β > 30:1).[14b] However, using *tert*-butanol as a nucleophile, the rearrangement product was not detected, probably due to its steric hinderance. Phenol was successfully converted into the corresponding 2-nitro-2,3-unsaturated phenolic glycoside with 0.15 equivalent of K_2CO_3. Nevertheless, the corresponding 2, 3-unsaturated glycoside decomposed rapidly under the Barton-Zard conditions. The attempts to prepare *S*-glycosides using benzyl mercaptan were not successful, with almost no formation of the rearrangement products.

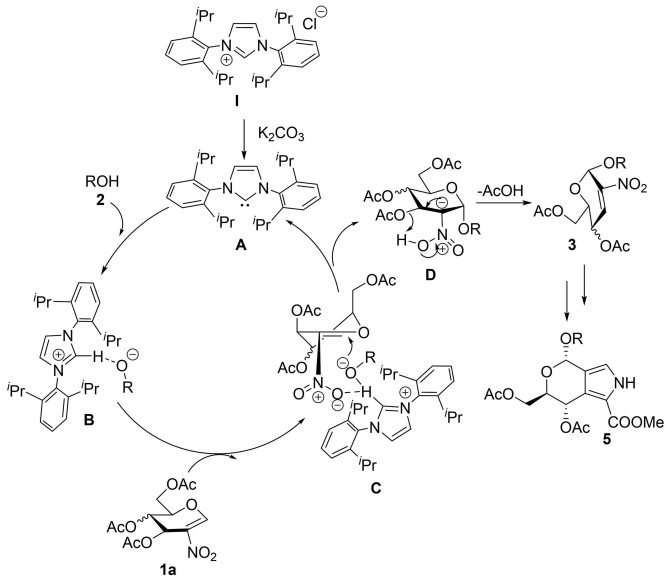
After evaluating the universality of the substrate, the practical synthesis of chiral pyrrole *via* "one-pot" strategy was investigated.[18,21] First, gram-scale **1a** and **2a** underwent the Ferrier rearrangement reaction, as shown in Scheme 2. After the completion of the reaction, **4** and Cs_2CO_3 were added into the reaction mixture, and the desired product **5a** was obtained with a total yield of 74%. For the first time, the conversion from nitroglycal to chiral pyrrole was successfully realized in one pot. As compared with the total yield of 82% in two step process, the one-pot strategy was comparable, which also afforded the use of affordable toluene. The gram-scale one-pot synthesis fully illustrated the applicability of the proposed novel method for the synthesis of chiral pyrrole.

The Ferrier rearrangement of glycals is usually known to generate the α:β anomeric mixtures of products in acidic conditions.[12b] However, in this study, the Ferrier rearrangement of nitroglycal formed the sole α anomers in the basic conditions, which were not altered during the subsequent Barton-Zard reactions. In order to explore the mechanism of the reaction, a series of glycal donors was further investigated. As previously shown, acetylated galactal reacted smoothly in the presence of NHC, thus, forming **5t–5u**. However, no Ferrier rearrangement products were detected once the protective group on the sugar ring was replaced with the benzyl group, which is a poor leaving group for the conditions in this study.[22] The same phenomenon took place on substituting the nitro group at the C-2 position by Cl or H, which indicated that both acetyl group and nitro substitution on the sugar ring were essential in the rearrangement step.

Based on the obtained findings and literature studies, a reaction mechanism may be proposed as follows (Scheme 3).[11,13,20] Firstly, NHC (I) is deprotonated in the presence of potassium carbonate to generate carbene A, which interacts with the hydroxyl group of the nucleophiles through hydrogen bonding to generate NHC-HOR complex B. After-



Scheme 2. One-pot Synthesis of Chiral Pyrrole **5a** by gram scale-up reaction.



Scheme 3. Proposed Mechanism.

wards, complex B and nitro group of nitroglycal **1a** form complex C through hydrogen bonding. Subsequently, the alkoxy group in complex C undergoes nucleophilic addition from the α surface of the sugar ring which has less steric hindrance to the anomeric center, and at the same time the protons in the alcohol are transferred to the nitro group to form a stable carbanion D. Simultaneously, the organic catalyst A is regenerated. Finally, complex D undergoes an elimination to get rid of acetic acid, thereby producing 2-nitro-2,3-unsaturated glycoside 3. Further, 3 undergoes a classic Barton-Zard reaction process to form the final pyrrole product 5.

Conclusion

In summary, a general strategy has been successfully developed for the synthesis of structurally diverse chiral pyrrole molecules without using the transition metal catalysts. In this context, the NHC-catalyzed Ferrier rearrangement was first successfully achieved with acetylated nitroglycals and a series of *O*-nucleophiles in basic conditions. The as-developed 2-nitro-2,3-unsaturated glycosides were subsequently applied as an alkyne equivalent during the [3 + 2] *N*-heterocyclic addition to form pyrrole-fused skeletons in mild conditions. By employing this novel strategy, βsubstituted chiral pyrroles were effectively synthesized with excellent yields and high stereoselectivity. To further demonstrate the practicability of the proposed methodology, the gram-scale Ferrier rearrangement of 2-nitroglycals and Barton-Zard reaction were successfully demonstrated in one pot. Overall, the innovative transformation reported in this study is expected to find widespread applications in the synthesis of pyrrole-containing natural products and drugs.

Experimental Section

General information: All reactions were carried out under dry nitrogen atmosphere. All solvents and reagents were obtained from commercial sources unless otherwise stated and were purified according to standard procedures. All NHC catalysts were purchased from the Energy Chemical Inc. (China). Removal of solvent *in vacuo* refers to distillation using a rotary evaporator attached to an efficient vacuum pump. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker DRX-500 NMR spectrometer in solutions of $CDCl_3$ using tetramethylsilane as the internal standard. Mass spectra were determined on LTQ-XL (Thermo scientific, USA) with an (ESI) Ion trap mass spectrometer. Optical rotations were measured using a polarimeter at 25 °C.

General procedure for the synthesis of 2-nitroglycal:[14b] To a stirred solution of a glycal (1 mmol) and $AgNO_3$ (1 mmol) in acetonitrile (10.0 mL) at 0 °C was added dropwise acetyl chloride (1 mmol). After the completion of the addition, the reaction was stirred at 55 °C monitored by TLC (PE/EA, 2 : 1) until the glycal donor was consumed completely. The reaction mixture was brought to room temperature and was neutralized to pH 7 by the addition of solid $NaHCO_3$. The suspension was filtered and concentrated. The solvent was removed under reduced pressure to afford a crude product which was purified by silica gel flash chromatography with a gradient solvent system (PE/EA, 4 : 1) to yield 2-nitroglycals.

General procedure for the synthesis of 2-nitro-2,3-unsaturated glycosides: To a mixture of 2-nitroglycal (63.4 mg, 0.2 mmol), alcohol acceptor (0.4 mmol), NHC (**I**) (4.3 mg, 0.01 mmol) and K_2CO_3 (1.4 mg, 0.01 mmol) were added toluene (2.0 mL) under an atmosphere of nitrogen. The reaction mixture was stirred at room temperature and monitored by TLC (PE/EA, 2 : 1) until the glycal donor was consumed completely. The solvent was removed under reduced pressure to afford a crude product which was purified by silica gel flash chromatography with a gradient solvent system (PE/EA, 4 : 1) to yield 2-nitro-2, 3-unsaturated glycosides.

General procedure for the synthesis of chiral pyrroles: To a mixture of 2-nitro-2,3-unsaturated glycoside (0.1 mmol), methyl isocyanoacetate (12.0 mg, 0.12 mmol) and Cs_2CO_3 (65.2 mg, 0.2 mmol) were reacted in THF under an atmosphere of nitrogen. The reaction mixture was stirred at room temperature and monitored by TLC (PE/EA, 2 : 1) until the 2-nitro-2,3-unsaturated glycoside was consumed completely. The solvent was removed under reduced pressure to afford a crude product which was purified by silica gel flash chromatography with a gradient solvent system (PE/EA, 2 : 1) to yield chiral pyrroles.

((2R,3S,6S)-3-acetoxy-6-(benzyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 a):[14b] Colorless syrup. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38–7.32 (m, 5H), 7.20 (d, J = 2.2 Hz, 1H), 5.71 (s, 1H), 5.59 (dd, J = 9.3, 1.7 Hz, 1H), 4.84 (d, J = 11.2 Hz, 1H), 4.76 (d, J = 11.2 Hz, 1H), 4.30–4.23 (m, 2H), 4.18 (t, J = 7.4 Hz, 1H), 2.13 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 148.1, 136.4, 132.9, 128.6, 128.4, 128.4, 92.0, 71.9, 66.6, 64.5, 62.0, 20.8, 20.7. HRMS (ESI): m/z Calcd for $C_{17}H_{19}NNaO_8$ $[M+Na]^+$: 388.1003, found 388.1013.

((2R,3S,6S)-3-acetoxy-6-((4-methoxybenzyl)oxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 b):[14b] Colorless syrup. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29 (d, *J* = 8.5 Hz, 2H), 7.18 (d, *J* = 2.1 Hz, 1H), 6.89 (d, *J* = 8.5 Hz, 2H), 5.67 (s, 1H), 5.57 (dd, *J* = 9.7, 1.3 Hz, 1H)„ 4.78 (d, *J* = 10.9 Hz, 1H), 4.67 (d, *J* = 10.9 Hz, 1H), 4.34–4.17 (m, 3H), 3.80 (s, 3H), 2.12 (s, 3H), 2.12 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 159.8, 148.2, 132.8, 130.1, 128.4, 114.0, 91.6, 71.5, 66.47, 64.5, 62.0, 55.3, 20.8, 20.7. HRMS (ESI): m/z Calcd for $C_{18}H_{21}NNaO_9$ $[M+Na]^+$: 418.1109, found 418.1111.

((2R,3S,6S)-3-acetoxy-6-((4-chlorobenzyl)oxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl) methyl acetate (3c): Colorless syrup. [α]25 D = + 13.2 (c 0.83, CH_2Cl_2). IR (neat) ν_{max} 2920, 1742, 1532, 1372, 1215, 1105, 1018, 732 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.35–7.28 (m, 4H), 7.21 (d, J = 2.2 Hz, 1H), 5.67 (s, 1H), 5.61–5.55 (dd, 1H), 4.81 (d, J = 11.5 Hz, 1H), 4.71 (d, J = 11.5 Hz, 1H), 4.28–4.20 (m, 3H), 2.14 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 147.9, 134.9, 134.3, 133.1, 129.7, 128.8, 91.9, 71.0, 66.7, 64.5, 62.0, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{17}H_{18}ClNNaO_9$ $[M+Na]^+$: 422.0613, found 422.0611.

((2R,3S,6S)-3-acetoxy-6-((2-iodobenzyl)oxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3d): Colorless syrup. [α]25 D = + 78.8 (c 0.21, CH_2Cl_2). IR (neat) ν_{max} 2921, 1735, 1529, 1370, 1211, 1104, 1013, 600 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, J = 7.9 Hz, 1H), 7.43 (d, J = 7.5 Hz, 1H), 7.36 (t, J = 7.5 Hz, 1H), 7.23 (d, J = 2.0 Hz, 1H), 7.02 (t, J = 7.6 Hz, 1H), 5.75 (s, 1H), 5.63–5.58 (m, 1H), 4.92 (d, J = 11.9 Hz, 1H), 4.74 (d, J = 12.0 Hz, 1H), 4.35 (ddd, J = 9.6, 4.7, 2.4 Hz, 1H), 4.28 (dd, J = 12.3, 4.9 Hz, 1H), 4.22 (dd, J = 12.3, 2.2 Hz, 1H), 2.14 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 147.9, 139.4, 138.9, 133.1, 129.9, 129.7, 128.5, 98.3, 92.0, 75.5, 66.8, 64.4, 62.0, 20.9, 20.8. HRMS (ESI): m/z Calcd for $C_{17}H_{18}INNaO_9$ $[M+Na]^+$: 513.9969, found 513.9977.

((2R,3S,6S)-3-acetoxy-6-methoxy-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3e):[14b] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) 1H NMR (500 MHz, CDCl3) δ 7.18 (d, J = 2.2 Hz, 1H), 5.57 (dd, J = 9.7, 1.4 Hz, 1H), 5.47 (s, 1H), 4.26 (t, J = 3.4 Hz, 2H), 4.21 (ddd, J = 9.5, 4.6, 2.8 Hz, 1H), 3.55 (s, 3H), 2.14 (s, 3H), 2.10 (s,3H). ^{13}C NMR (126 MHz, CDCl3) δ 170.6, 169.8, 148.1, 132. 7, 93.4, 66.3, 64.4, 62.0, 57.0, 20.7. HRMS (ESI): m/z Calcd for $C_{11}H_{15}NNaO_8$ $[M+Na]^+$: 312.0690, found 312.0694.

((2R,3S,6S)-3-acetoxy-6-ethoxy-5-nitro-3,6-dihydro-2H-pyran-2-yl) methyl acetate (3f): Colorless syrup. [α]25 D = + 144.2 (c 2.84, CH_2Cl_2). IR (neat) ν_{max} 2923, 1742, 1535, 1369, 1215, 1111, 1022 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.16 (d, J = 2.0 Hz, 1H), 5.60–5.53 (m, 2H), 4.29–4.22 (m, 3H), 3.93–3.85 (m, 1H), 3.79–3.71 (m, 1H), 2.14 (s, 3H), 2.10 (s, 3H), 1.26 (t, J = 7.1 Hz, 3H). ^{13}C NMR (126 MHz, CDCl3) δ 170.7, 169.9, 148.4, 132.5, 92.2, 66.4, 65.8, 64.5, 62.1, 20.8, 15.1. HRMS (ESI): m/z Calcd for $C_{12}H_{17}NNaO_8$ $[M+Na]^+$: 326.0846, found 326.0849.

((2R,3S,6S)-3-acetoxy-6-isobutoxy-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3g): Colorless syrup. [α]25 D = + 80.6 (c 2.00, CH_2Cl_2). IR (neat) ν_{max} 2962, 1738, 1532, 1364, 1214, 1107, 1016 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.16 (d, J = 2.2 Hz, 1H), 5.57–5.52 (m, 2H), 4.26–4.21 (m, 3H), 3.58 (dd, J = 9.1, 6.8 Hz, 1H), 3.46 (dd, J = 9.1, 6.4 Hz, 1H), 2.14 (s, 3H), 2.09 (s, 3H), 1.90 (dt, J = 13.3, 6.7 Hz, 1H), 0.91 (dd, J = 6.7, 2.7 Hz, 6H). ^{13}C NMR (126 MHz, CDCl3) δ 170.6, 169.8, 148.3, 132.5, 92.5, 77.0, 66.4, 64.51, 62.1, 28.4, 20.8, 19.3, 19.2. HRMS (ESI): m/z Calcd for $C_{14}H_{21}NNaO_8$ $[M+Na]^+$: 354.1159, found 354.1153.

((2R,3S,6S)-3-acetoxy-6-(hexyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3h): Colorless syrup. [α]25 D = + 75.2 (c 3.20, CH_2Cl_2). IR (neat) ν_{max} 2926, 1742, 1538, 1366, 1218, 1111, 1022 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.16 (d, J = 2.1 Hz, 1H), 5.55 (d, J = 5.2 Hz, 2H), 4.27–4.20 (m, 3H), 3.84–3.77 (m, 1H), 3.67 (dt, J = 9.4, 6.5 Hz, 1H), 2.13 (s, 3H), 2.09 (s, 3H), 1.60 (dd, J = 13.9, 6.9 Hz, 2H), 1.30 (dd, J = 20.9, 6.2 Hz, 6H), 0.87 (t, J = 6.6 Hz, 3H).). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 148.3, 132.4, 92.4, 70.4, 66.4, 64.5, 62.1, 31.5, 29.4, 25.7, 22.6, 20.8, 14.1. HRMS (ESI): m/z Calcd for $C_{16}H_{25}NNaO_8$ $[M+Na]^+$: 382.1472, found 382.1468.

((2R,3S,6S)-3-acetoxy-6-(2-bromoethoxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3i): Colorless syrup. [α]25 D = + 49.6 (c 0.31, CH_2Cl_2). IR (neat) ν_{max} 2956, 1738, 1529, 1349, 1217, 1107, 1022 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.21 (d, J = 2.1 Hz, 1H), 5.61 (s, 1H), 5.59–5.55 (m, 1H), 4.34 (ddd, J = 9.7, 4.8, 2.5 Hz, 1H), 4.30–4.24 (m, 2H), 4.09 (t, J = 5.9 Hz, 2H), 3.57–3.49 (m, 2H), 2.15 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 147.6, 133.2, 92.4, 70.0, 66.9, 64.3, 61.9, 30.0, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{12}H_{16}BrNNaO_8$ $[M+Na]^+$: 403.9951, found 403.9952.

((2R,3S,6S)-3-acetoxy-5-nitro-6-(2,2,2-tribromoethoxy)-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3j): Colorless syrup. [α]25 D = + 106.1 (c 0.49, CH_2Cl_2). IR (neat) ν_{max} 2962, 1738, 1532, 1370, 1208, 1084, 1019, 630 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.31 (d, J = 2.1 Hz, 1H), 5.83 (s, 1H), 5.63 (dd, J = 9.9, 1.3 Hz, 1H), 4.59 (d, J = 10.9 Hz, 1H), 4.53 (d, J = 10.9 Hz, 1H), 4.46 (ddd, J = 10.2, 4.8, 2.4 Hz, 1H), 4.32 (dd, J = 12.4, 2.4 Hz, 1H), 4.27 (dd, J = 12.4, 5.0 Hz, 1H), 2.17 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 146.9, 134.0, 91.7, 83.4, 67.5, 64.3, 61.8, 36.4, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{12}H_{14}Br_3NNaO_8$ $[M+Na]^+$: 559.8162, found 559.8168.

(2R,3S,6S)-6-((9H-fluoren-9-yl)methoxy)-2-(acetoxymethyl)-5-nitro-3,6-dihydro-2H-pyran-3-yl acetate (3k): Colorless syrup. [α] 25 D = + 145.3 (c 2.12, CH_2Cl_2). IR (neat) ν_{max} 3068, 1742, 1532, 1370, 1216, 1104, 1019 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.77 (d, J = 7.6 Hz, 2H), 7.57 (dd, J = 13.4, 7.5 Hz, 2H), 7.40 (td, J = 7.4, 2.2 Hz, 2H), 7.31 (dt, J = 16.1, 7.5 Hz, 2H), 7.25 (d, J = 1.9 Hz, 1H), 5.68 (s, 1H), 5.59–5.54 (m, 1H), 4.23–4.15 (m, 4H), 4.06 (dd, J = 7.0, 2.7 Hz, 2H), 2.18 (s, 3H), 1.95 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.5, 169.8, 148.0, 144.4, 144.0, 141.3, 133.0, 127.8, 127.8, 127.2, 127.1, 125.2, 125.0, 120.1, 120.0, 92.6, 77.3, 72.4, 66.8, 64.5, 61.9, 47.6, 20.8, 20.6. HRMS (ESI): m/z Calcd for $C_{24}H_{23}NNaO_9$ $[M+Na]^+$: 476.1316, found 476.1323.

((2R,3S,6S)-3-acetoxy-5-nitro-6-(prop-2-yn-1-yloxy)-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3l): Colorless syrup. [α]25 D = + 195.3 (c 1.22, CH_2Cl_2). IR (neat) ν_{max} 2927, 1738, 1532, 1370, 1214, 1016, 659 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.22 (d, J = 2.2 Hz, 1H), 5.78 (s, 1H), 5.60 (dd, J = 9.0, 1.9 Hz, 1H), 4.42 (dd, J = 15.6, 2.4 Hz, 1H), 4.38 (dd, J = 15.6, 2.4 Hz, 1H), 4.29–4.24 (m, 3H), 2.54 (t, J = 2.4 Hz, 1H), 2.14 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.50, 169.68, 147.60, 133.17, 91.03, 77.86, 75.70, 66.63, 64.25, 61.71, 56.37, 20.67, 20.65.

((2R,3S,6S)-3-acetoxy-6-(allyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3m):[14b] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) δ 7.19 (d, J = 2.2 Hz, 1H), 6.01–5.90 (m, 1H), 5.63 (s, 1H), 5.61–5.55 (m, 1H), 5.34 (dd, J = 17.2, 1.5 Hz, 1H), 5.26 (dd, J = 10.4, 1.2 Hz, 1H), 4.32 (dd, J = 12.5, 5.5 Hz, 1H), 4.29–4.20 (m, 4H), 2.15 (s, 3H), 2.11 (s, 3H).

((2R,3S,6S)-3-acetoxy-6-(cinnamyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3n): Colorless syrup. [α]25 D = + 33.7 (c 1.93, CH_2Cl_2). IR (neat) ν_{max} 3024, 1741, 1535, 1370, 1216, 1087, 1007 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.41 (d, J = 7.3 Hz, 2H), 7.33 (t, J = 7.5 Hz, 2H), 7.26 (d, J = 1.9 Hz, 1H), 7.21 (d, J = 2.2 Hz, 1H), 6.66 (d, J = 15.9 Hz, 1H), 6.35–6.28 (m, 1H), 5.71 (s, 1H), 5.60 (dd, J = 9.3, 1.4 Hz, 1H), 4.49 (ddd, J = 12.3, 5.9, 1.3 Hz, 1H), 4.42–4.38 (m, 1H), 4.30 (dt, J = 8.8, 3.4 Hz, 3H), 2.15 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 169.8, 148.3, 136.3, 134.3, 132.8, 128.7, 128.2, 126.7, 124.1, 91.3, 70.2, 66.5, 64.5, 62.1, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{19}H_{21}NNaO_8$ $[M+Na]^+$: 414.1159, found 414.1156.

((2R,3S,6S)-3-acetoxy-6-(furan-2-ylmethoxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3o) Colorless syrup. [α]25 D = + 83.4 (c 2.01, CH_2Cl_2). IR (neat) ν_{max} 2921, 1741, 1532, 1370, 1216, 1107, 1013 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 7.52 (dd, J = 1.9, 0.8 Hz, 1H), 7.26 (d, J = 2.3 Hz, 1H), 6.48 (d, J = 3.2 Hz, 1H), 6.45 (dd, J = 3.3, 1.9 Hz, 1H), 5.77 (s, 1H), 5.69–5.65 (m, 1H), 4.81 (q, J = 12.7 Hz, 2H), 4.37–4.31 (m, 2H), 4.30–4.25 (m, 1H), 2.21 (s, 3H), 2.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 170.57, 169.74, 150.07, 147.88, 143.39, 132.88, 110.53, 110.44, 91.34, 66.46, 64.28, 63.04, 61.81,

20.71, 20.67. HRMS (ESI): m/z Calcd for $C_{15}H_{17}NNaO_9$ $[M+Na]^+$: 378.0796, found 378.0804.

((2R,3S,6S)-3-acetoxy-5-nitro-6-(((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-5H-bis([1,3]dioxolo)[4,5-b:4′,5′-d]pyran-5-yl)methoxy)-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 p): Colorless syrup. [α]25 D = +21.3 (c 2.15, CH_2Cl_2). IR (neat) ν_{max} 2986, 1744, 1540, 1367, 1211, 1066, 1001 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.19 (d, *J* = 2.2 Hz, 1H), 5.62 (s, 1H), 5.60–5.55 (m, 1H), 5.51 (d, *J* = 5.0 Hz, 1H), 4.60 (dd, *J* = 7.9, 2.3 Hz, 1H), 4.32–4.27 (m, 3H), 4.26–4.20 (m, 2H), 3.99–3.86 (m, 3H), 2.14 (s, 3H), 2.10 (s, 3H), 1.51 (s, 3H), 1.44 (s, 3H), 1.34 (s, 3H), 1.32 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.7, 169.9, 148.0, 133.1, 109.4, 108.7, 96.4, 92.8, 71.0, 70.7, 70.6, 69.0, 66.8, 66.4, 64.4, 62.0, 26.1, 26.0, 25.0, 24.4, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{22}H_{31}NNaO_{13}$ $[M+Na]^+$: 540.1688, found 540.1681.

((2R,3S,6S)-3-acetoxy-6-(((3S,8S,9S,10R,13R,14S,17R)-10,13-dimethyl-17-((R)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)oxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl) methyl acetate (3 q): White solid. [α]25 D = +138.4 (c 0.41, CH_2Cl_2). IR (neat) ν_{max} 2933, 1732, 1532, 1367, 1228, 1101, 1025 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.16 (d, *J* = 2.2 Hz, 1H), 5.71 (s, 1H), 5.54 (dd, *J* = 9.7, 1.6 Hz, 1H), 5.37 (d, *J* = 5.2 Hz, 1H), 4.35–4.30 (m, 1H), 4.26 (dd, *J* = 9.6, 7.3 Hz, 2H), 3.65 (ddd, *J* = 16.2, 11.1, 4.8 Hz, 1H), 2.42–2.33 (m, 2H), 2.15 (s, 3H), 2.10 (s, 3H), 2.05–1.95 (m, 41H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.7, 169.9, 148.7, 140.5, 132.3, 122.4, 91.1, 80.3, 66.4, 64.7, 62.3, 56.8, 56.2, 50.2, 42.4, 40.3, 39.8, 39.6, 37.1, 36.8, 36.3, 35.9, 32.0, 32.0, 28.3, 28.1, 27.9, 24.4, 23.9, 22.9, 22.7, 21.1, 20.8, 20.8, 19.4, 18.8, 12.0. HRMS (ESI): m/z Calcd for $C_{37}H_{57}NNaO_8$ $[M+Na]^+$: 666.3976, found 666.3987.

((2R,3S,6S)-3-acetoxy-6-isopropoxy-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 r):[14a] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) δ 7.15 (d, *J* = 2.2 Hz, 1H), 5.66 (s, 1H), 5.55 (dd, *J* = 9.3, 1.8 Hz, 1H), 4.31–4.27 (m, 1H), 4.27–4.23 (m, 2H), 4.07 (m, *J* = 6.2 Hz, 1H), 2.14 (s, 3H), 2.10 (s, 3H), 1.25 (dd, *J* = 14.6, 6.2 Hz, 6H). ^{13}C NMR (126 MHz, CDCl3) δ170.6, 169.8, 148.6, 132.2, 91.2, 73.2, 66.2, 64.6, 62.2, 23.3, 21.7, 20.7, 20.7. HRMS (ESI): m/z Calcd for $C_{13}H_{19}NNaO_8$ $[M+Na]^+$: 340.1003, found 340.1007.

((2R,3S,6S)-3-acetoxy-6-(cyclohexyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 s):[14b] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) ^1H NMR (500 MHz, $CDCl_3$) δ 7.15 (d, *J* = 2.2 Hz, 1H), 5.70 (s, 1H), 5.55 (ddd, *J* = 9.7, 2.2, 0.8 Hz, 1H), 4.32–4.28 (m, 1H), 4.27–4.23 (m, 2H), 3.77 (td, *J* = 9.0, 4.5 Hz, 1H), 2.14 (s, 3H), 2.09 (s, 3H), 1.92 (s, 2H), 1.74–1.70 (m, 2H), 1.43–1.23 (m, 6H). ^{13}C NMR (126 MHz, $CDCl^3$) δ 170.6, 169.9, 148.7, 132.2, 91.2, 78.7, 66.3, 64.7, 62.3, 33.5, 31.6, 25.5, 24.0, 23.8, 20.8, 20.8. HRMS (ESI): m/z Calcd for $C_{16}H_{23}NNaO_8$ $[M+Na]^+$: 380.1316, found 380.1319.

((2R,3R,6S)-3-acetoxy-6-(benzyloxy)-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 t):[14b] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) δ 7.36 (dd, *J* = 8.7, 4.1 Hz, 5H), 7.29 (d, *J* = 5.6 Hz, 1H), 5.78 (s, 1H), 5.40 (dd, *J* = 5.6, 2.8 Hz, 1H), 4.84 (d, *J* = 11.2 Hz, 1H), 4.73 (d, *J* = 11.2 Hz, 1H), 4.49–4.45 (m, 1H), 4.28 (dd, *J* = 11.5, 5.5 Hz, 1H), 4.23 (dd, *J* = 11.5, 7.3 Hz, 1H), 2.12 (s, 3H), 2.09 (s, 3H).

((2R,3R,6S)-3-acetoxy-6-methoxy-5-nitro-3,6-dihydro-2H-pyran-2-yl)methyl acetate (3 u):[14b] Colorless syrup. ^1H NMR (500 MHz, $CDCl_3$) δ 7.27 (d, *J* = 4.2 Hz, 1H), 5.55 (s, 1H), 5.39 (dd, *J* = 5.6, 2.8 Hz, 1H), 4.41–4.36 (m, 1H), 4.29–4.26 (m, 2H), 3.54 (s, 3H), 2.12 (s, 3H), 2.09 (s, 3H).

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(benzyloxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 a): Colorless syrup. [α]25 D = −27.1 (c 2.00, CH_2Cl_2). IR (neat) ν_{max} 3298, 3030, 2950, 1710, 1581, 1440, 1227, 1153, 1006, 729, 698 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 9.49 (s, 1H), 7.40–7.33 (m, 4H), 7.29 (t, *J* = 7.1 Hz, 1H), 6.87 (d, *J* = 3.0 Hz, 1H), 6.27 (d, *J* = 8.9 Hz, 1H), 5.77 (s, 1H), 4.84 (t, *J* = 10.2 Hz, 1H), 4.71–4.67 (m, 1H), 4.25 (ddd, *J* = 24.0, 14.7, 7.6 Hz, 3H), 3.78 (s, 3H), 2.10 (s, 3H), 2.08 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.6, 137.6, 128.6, 128.1, 127.9, 123.2, 121.8, 118.8, 118.6, 93.4, 69.7, 68.6, 63.1, 51.8, 20.9, 20.9. HRMS (ESI): m/z Calcd for $C_{21}H_{23}NNaO_8$ $[M+Na]^+$: 440.1316, found 440.1311.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-((4-methoxybenzyl)oxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 b): Colorless syrup. [α]25 D = −30.3 (c 2.05, CH_2Cl_2). IR (neat) ν_{max} 3307, 3030, 2953, 1735, 1612, 1233, 1153, 1012, 729 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 9.29 (s, 1H), 7.31 (d, *J* = 8.5 Hz, 2H), 6.89 (d, *J* = 8.5 Hz, 2H), 6.85 (d, *J* = 3.1 Hz, 1H), 6.27 (d, *J* = 8.6 Hz, 1H), 5.75 (s, 1H), 4.78 (d, *J* = 11.4 Hz, 1H), 4.62 (d, *J* = 11.4 Hz, 1H), 4.33–4.22 (m, 3H), 3.80 (s, 3H), 3.78 (s, 3H), 2.12 (s, 3H), 2.08 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 159.5, 129.8, 129.7, 123.3, 122.0, 118.8, 118.4, 114.0, 93.1, 77.4, 77.1, 76.9, 69.4, 68.5, 63.2, 63.1, 55.4, 51.8, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{22}H_{25}NNaO_9$ $[M+Na]^+$: 470.1422, found 470.1430.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-((4-chlorobenzyl)oxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 c): Colorless syrup. [α]25 D = −27.1 (c 1.22, CH_2Cl_2). IR (neat) ν_{max} 3301, 3030, 2950, 1735, 1581, 1230, 1156, 1006, 803, 769 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 9.34 (d, *J* = 22.0 Hz, 1H), 7.32 (s, 4H), 6.87 (d, *J* = 3.0 Hz, 1H), 6.27 (d, *J* = 8.7 Hz, 1H), 5.75 (s, 1H), 4.82 (d, *J* = 12.0 Hz, 1H), 4.65 (d, *J* = 12.0 Hz, 1H), 4.32–4.21 (m, 3H), 3.79 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 136.1, 133.7, 129.4, 128.8, 123.2, 121.6, 118.9, 118.5, 93.4, 68.9, 68.7, 63.1, 63.1, 51.9, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{21}H_{22}ClNNaO_8$ $[M+Na]^+$: 474.0926, found 474.0936.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-((2-iodobenzyl)oxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 d): Colorless syrup. [α]25 D = −7.4 (c 1.96, CH_2Cl_2). IR (neat) ν_{max} 3301, 3052, 2950, 1732, 1584, 1440, 1227, 1006, 735, 566 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 9.34 (s, 1H), 7.84 (dd, *J* = 7.9, 0.9 Hz, 1H), 7.45 (dd, *J* = 7.6, 1.4 Hz, 1H), 7.34 (td, *J* = 7.5, 0.9 Hz, 1H), 7.00 (td, *J* = 7.7, 1.6 Hz, 1H), 6.96 (d, *J* = 3.1 Hz, 1H), 6.29 (d, *J* = 8.6 Hz, 1H), 5.85 (s, 1H), 4.85 (d, *J* = 12.5 Hz, 1H), 4.67 (d, *J* = 12.5 Hz, 1H), 4.29 (ddd, *J* = 19.4, 11.4, 7.6 Hz, 3H), 3.79 (s, 3H), 2.11 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 140.0, 139.4, 129.6, 129.4, 128.4, 123.3, 121.7, 118.9, 118.6, 98.3, 94.1, 73.8, 68.9, 63.2, 63.1, 51.9, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{21}H_{22}INNaO_8$ $[M+Na]^+$: 566.0282, found 566.0275.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-methoxy-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5 e): Colorless syrup. [α]25 D = −11.4 (c 1.33, CH_2Cl_2). IR (neat) ν_{max} 3298, 3040, 2953, 1704, 1440, 1372, 1332, 1230, 1018, 735 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 9.31 (s, 1H), 6.90 (d, *J* = 3.1 Hz, 1H), 6.26 (d, *J* = 9.2 Hz, 1H), 5.58 (s, 1H), 4.29 (d, *J* = 4.6 Hz, 2H), 4.20–4.15 (m, 1H), 3.79 (s, 3H), 3.51 (s, 3H), 2.12 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 123.1, 121.9, 118.9, 118.4, 95.2, 68.4, 63.2, 63.1, 55.3, 51.8, 21.0, 20.9. HRMS (ESI): m/z Calcd for $C_{15}H_{19}NNaO_8$ $[M+Na]^+$: 364.1003, found 364.1005.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-ethoxy-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5 f): Colorless syrup. [α]25 D = −70.2 (c 2.11, CH_2Cl_2). ^1H NMR (600 MHz, $CDCl_3$) δ 9.21 (s, 1H), 6.89 (d, *J* = 3.0 Hz, 1H), 6.26 (d, *J* = 9.1 Hz, 1H), 5.69 (s, 1H), 4.29 (d, *J* = 4.1 Hz, 2H), 4.22 (dt, *J* = 8.5, 4.1 Hz, 1H), 3.90–3.85 (m, 1H), 3.79 (s, 3H), 3.71–3.65 (m, 1H), 2.11 (s, 3H), 2.09 (s, 3H), 1.29 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.6, 123.2, 122.2, 118.9, 118.4, 94.0, 68.3, 63.6, 63.2, 63.1, 51.8, 21.0, 20.9, 15.3. HRMS (ESI): m/z Calcd for $C_{16}H_{21}NNaO_8$ $[M+Na]^+$: 378.1159, found 378.1162.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-isobutoxy-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5 g): Colorless syrup. [α]25 D = −15.6 (c 1.00, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.35 (s, 1H), 6.88 (d, *J* = 3.1 Hz, 1H), 6.25 (d, *J* = 9.1 Hz, 1H), 5.65 (s, 1H), 4.28 (d, *J* = 4.2 Hz, 2H), 4.23–4.17 (m, 1H), 3.79 (s, 3H), 3.58 (dd, *J* = 9.3, 7.0 Hz, 1H), 3.38 (dd, *J* = 9.3, 6.5 Hz, 1H), 2.11 (s, 3H), 2.09 (s, 3H), 1.92 (td, *J* = 13.4, 6.7 Hz, 1H), 0.94 (d, *J* = 6.7 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.8, 170.4, 160.5, 123.1, 122.1, 118.7, 118.3, 94.2, 75.0, 68.3, 63.2, 63.1, 51.7, 28.4, 20.9, 20.8, 19.5, 19.4. HRMS (ESI): m/z Calcd for $C_{18}H_{25}NNaO_8$ $[M+Na]^+$: 406.1472, found 406.1484.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(hexyloxy)-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5 h): Colorless syrup. [α]25 D = −18.7 (c 0.98, CH_2Cl_2). IR (neat) ν_{max} 3307, 3030, 2953, 1738, 1440, 1233, 1009, 729 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.29 (s, 1H), 6.88 (d, *J* = 3.1 Hz, 1H), 6.26 (d, *J* = 9.1 Hz, 1H), 5.67 (s, 1H), 4.31–4.26 (m, 2H), 4.23–4.18 (m, 1H), 3.84–3.80 (m, 1H), 3.79 (s, 3H), 3.59 (dt, *J* = 9.5, 6.6 Hz, 1H), 2.11 (s, 3H), 2.09 (s, 3H), 1.63 (dd, *J* = 14.4, 7.4 Hz, 2H), 1.39–1.29 (m, 6H), 0.88 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.6, 123.2, 122.2, 118.8, 118.4, 94.1, 68.4, 68.3, 63.3, 63.2, 51.8, 31.7, 29.7, 26.0, 22.7, 21.0, 20.90, 14.1. HRMS (ESI): m/z Calcd for $C_{20}H_{29}NNaO_8$ $[M+Na]^+$: 434.1785, found 434.1775.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(2-bromoethoxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 i): Colorless syrup. [α]25 D = −79.2 (c 0.31, CH_2Cl_2). IR (neat) ν_{max} 3313, 3030, 2950, 1729, 1443, 1227, 1009, 732, 569 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.37 (s, 1H), 6.92 (d, *J* = 3.0 Hz, 1H), 6.25 (d, *J* = 8.0 Hz, 1H), 5.74 (s, 1H), 4.30–4.24 (m, 3H), 4.11 (dt, *J* = 11.9, 6.1 Hz, 1H), 4.02–3.95 (m, 1H), 3.79 (s, 3H), 3.57 (td, *J* = 6.1, 1.5 Hz, 2H), 2.12 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 123.1, 121.3, 118.9, 118.6, 94.6, 68.8, 68.2, 63.2, 63.0, 51.9, 30.6, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{16}H_{20}BrNNaO_8$ $[M+Na]^+$: 456.0264, found 456.0273.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(2,2,2-tribromoethoxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 j): Colorless syrup. [α]25 D = −7.3 (c 0.49, CH2Cl$_2$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.36 (s, 1H), 7.01 (d, *J* = 3.1 Hz, 1H), 6.29 (d, *J* = 9.2 Hz, 1H), 6.02 (s, 1H), 4.55 (d, *J* = 11.7 Hz, 1H), 4.47 (d, *J* = 11.7 Hz, 1H), 4.36–4.33 (m, 1H), 4.33–4.26 (m, 2H), 3.81 (s, 3H), 2.13 (s, 3H), 2.11 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.8, 170.5, 160.4, 123.3, 120.6, 118.9, 118.9, 94.6, 82.3, 69.4, 62.9, 51.9, 39.2, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{16}H_{18}Br_3NNaO_8$ $[M+Na]^+$: 611.8475, found 611.8489.

Methyl (4S,6R,7S)-4-((9H-fluoren-9-yl)methoxy)-7-acetoxy-6-(acetoxymethyl)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 k): Colorless syrup. [α]25 D = −8.3 (c 2.05, CH_2Cl_2). IR (neat) ν_{max} 3301, 3036, 2947, 1729, 1581, 1443, 1230, 1009, 726 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.34 (s, 1H), 7.77 (d, *J* = 7.5 Hz, 2H), 7.63 (dd, *J* = 12.4, 7.5 Hz, 2H), 7.40 (t, *J* = 6.6 Hz, 2H), 7.30 (q, *J* = 7.5 Hz, 2H), 6.88 (d, *J* = 3.0 Hz, 1H), 6.26 (d, *J* = 8.7 Hz, 1H), 5.73 (s, 1H), 4.24 (dt, *J* = 10.6, 4.0 Hz, 4H), 4.14 (dd, *J* = 9.3, 7.4 Hz, 1H), 3.85 (dd, *J* = 9.3, 7.7 Hz, 1H), 3.81 (s, 3H), 2.13 (s, 3H), 1.93 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.8, 170.5, 160.5, 144.9, 144.6, 141.4, 141.3, 127.7, 127.7, 127.1, 127.0, 125.3, 125.3, 123.2, 122.0, 120.0, 120.0, 118.9, 118.5, 94.7, 70.8, 68.8, 63.1, 51.9, 47.9, 21.0, 20.7. HRMS (ESI): m/z Calcd for $C_{28}H_{27}NNaO_8$ $[M+Na]^+$: 528.1629, found 528.1639.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(prop-2-yn-1-yloxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 l): Colorless syrup. [α]25 D = −11.3 (c 1.00, CH_2Cl_2). IR (neat) ν_{max} 3283, 3030, 2953, 1707, 1443, 1230, 1156, 1006, 732, 606 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.40 (s, 1H), 6.91 (d, *J* = 3.0 Hz, 1H), 6.28 (d, *J* = 9.2 Hz, 1H), 5.87 (s, 1H), 4.40–4.34 (m, 2H), 4.28 (d, *J* = 4.0 Hz, 2H), 4.22–4.17 (m, 1H), 3.79 (s, 3H), 2.48 (d, *J* = 2.3 Hz, 1H), 2.12 (s, 3H), 2.08 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.4, 160.5, 123.3, 121.2, 118.9, 118.7, 92.6, 79.2, 75.0, 68.7, 63.0, 54.6, 51.9, 20.9, 20.9. HRMS (ESI): m/z Calcd for $C_{17}H_{19}NNaO_8$ $[M+Na]^+$: 388.1003, found 388.1008.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(allyloxy)-2,4,6,7-tetrahydropyrano [3,4-c]pyrrole-1-carboxylate (5 m): Colorless syrup. [α]25 D = +164.4 (c 1.81, CH_2Cl_2). IR (neat) ν_{max} 3295, 3027, 2960, 1707, 1581, 1440, 1227, 1009, 726 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.30 (s, 1H), 6.90 (s, 1H), 6.27 (d, *J* = 9.1 Hz, 1H), 5.98 (ddd, *J* = 22.4, 10.9, 5.7 Hz, 1H), 5.72 (s, 1H), 5.33 (dd, *J* = 17.2, 1.5 Hz, 1H), 5.22 (dd, *J* = 10.4, 1.2 Hz, 1H), 4.31 (dd, *J* = 10.8, 3.3 Hz, 1H), 4.28 (d, *J* = 4.2 Hz, 2H), 4.25–4.20 (m, 1H), 4.17 (dd, *J* = 12.8, 6.2 Hz, 1H), 3.79 (s, 3H), 2.12 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 134.1, 123.3, 121.9, 118.9, 118.4, 117.7, 93.4, 68.7, 68.5, 63.2, 63.1, 51.9, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{17}H_{21}NNaO_8$ $[M+Na]^+$: 390.1159, found 390.1166.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(cinnamyloxy)-2,4,6,7-tetrahydropyrano [3,4-c]pyrrole-1-carboxylate (5 n): Colorless syrup. [α]25 D = −30.5 (c 1.12, CH_2Cl_2). IR (neat) ν_{max} 3301, 3024, 2956, 1704, 1581, 1443, 1224, 1009, 741 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.31 (s, 1H), 7.39 (d, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.6 Hz, 2H), 7.24 (d, *J* = 7.2 Hz, 1H), 6.92 (d, *J* = 3.1 Hz, 1H), 6.66 (d, *J* = 15.9 Hz, 1H), 6.38–6.32 (m, 1H), 6.29 (d, *J* = 9.0 Hz, 1H), 5.79 (s, 1H), 4.48 (ddd, *J* = 12.6, 5.7, 1.2 Hz, 1H), 4.37–4.33 (m, 1H), 4.33–4.29 (m, 2H), 4.29–4.24 (m, 1H), 3.80 (s, 3H), 2.13 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 136.6, 133.3, 128.7, 128.0, 126.6, 125.2, 123.3, 122.0, 119.0, 118.4, 93.3, 68.5, 68.3, 63.2, 63.1, 51.9, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{23}H_{25}NNaO_8$ $[M+Na]^+$: 466.1472, found 466.1473.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(furan-2-ylmethoxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 o): Colorless syrup. [α]25 D = −24.3 (c 1.02, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.20 (s, 1H), 7.42 (s, 1H), 6.86 (d, *J* = 1.6 Hz, 1H), 6.40–6.34 (m, 2H), 6.28 (d, *J* = 8.9 Hz, 1H), 5.78 (s, 1H), 4.75 (d, *J* = 12.7 Hz, 1H), 4.67 (d, *J* = 12.7 Hz, 1H), 4.32–4.23 (m, 3H), 3.79 (d, *J* = 1.4 Hz, 3H), 2.13 (d, *J* = 1.3 Hz, 3H), 2.08 (d, *J* = 1.4 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 151.1, 143.1, 123.3, 121.5, 118.8, 118.6, 110.5, 109.8, 93.1, 68.5, 63.1, 63.0, 61.3, 51.8, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{19}H_{21}NNaO_9$ $[M+Na]^+$: 430.1109, found 430.1120.

Methyl (6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(((3aS,5S,8bS)-2,2,7,7-tetra-methyltetrahydro -5H-bis([1,3]dioxolo)[4,5-b:4′,5′-d] pyran-5-yl)methoxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5 p): Colorless syrup. [α]25 D = −47.9 (c 2.07, CH_2Cl_2). IR (neat) ν_{max} 3304, 3030, 2987, 1729, 1440, 1372, 1230, 1064, 996, 726 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.23 (s, 1H), 6.90 (d, *J* = 2.9 Hz, 1H), 6.27 (d, *J* = 9.1 Hz, 1H), 5.74 (s, 1H), 5.53 (d, *J* = 5.0 Hz, 1H), 4.62 (dd, *J* = 7.9, 2.0 Hz, 1H), 4.33–4.23 (m, 5H), 4.04 (t, *J* = 6.3 Hz, 1H), 3.92 (dd, *J* = 10.3, 6.6 Hz, 1H), 3.86–3.83 (m, 1H), 3.79 (s, 3H), 2.13 (s, 3H), 2.08 (s, 3H), 1.50 (s, 3H), 1.45 (s, 3H), 1.35 (s, 3H), 1.32 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 171.0, 170.4, 160.5, 123.3, 122.0, 118.8, 118.5, 109.4, 108.7, 96.5, 94.2, 71.1, 70.8, 70.7, 68.5, 66.5, 66.2, 63.0, 63.0, 51.8, 26.1,26.1, 25.0, 24.7, 21.0. HRMS (ESI): m/z Calcd for $C_{26}H_{35}NNaO_{13}$ $[M+Na]^+$: 592.2001, found 592.2007.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(((3S,8S,9S,10R,13R,14S,17R)-10,13-dimethyl- 17-((R)-6-methylheptan-2-yl)-2,3,4,7,8,9,10,11,12,13,14,15,16,17- tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)oxy)-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5 q): White solid. [α]25 D = −7.6 (c 1.03, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.24 (s, 1H), 6.86 (d, *J* = 2.9 Hz, 1H), 6.27–6.21 (m, 1H), 5.83 (s, 1H), 5.37 (d, *J* = 4.6 Hz, 1H), 4.28 (s, 3H), 3.79 (s, 3H), 3.72–3.63 (m, 1H), 2.39 (t, *J* = 7.0 Hz, 2H), 2.10 (s, 3H), 2.09 (s, 3H), 1.98 (d, *J* = 21.2 Hz, 3H), 1.91–0.68 (m,

38H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 171.0, 170.6, 160.6, 140.8, 123.3, 122.5, 122.0, 118.9, 118.1, 92.3, 68.3, 63.38, 63.2, 56.8, 56.2, 51.8, 50.3, 42.4, 40.3, 39.9, 39.6, 37.3, 36.8, 36.3, 35.9, 32.0, 32.0, 28.3, 28.3, 28.10, 24.4, 23.9, 22.9, 22.7, 21.2, 21.0, 19.4, 18.8, 12.0. HRMS (ESI): m/z Calcd for $C_{41}H_{61}NNaO_8$ $[M+Na]^+$: 718.4289, found 718.4295.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-isopropoxy-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5r): Colorless syrup. [α]25 D = −16.0 (c 0.70, CH_2Cl_2). IR (neat) ν_{max} 3301, 3033, 2953, 1704, 1440, 1369, 1224, 996, 735 c ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.24 (s, 1H), 6.85 (d, *J* = 3.0 Hz, 1H), 6.25 (d, *J* = 9.0 Hz, 1H), 5.77 (s, 1H), 4.30–4.20 (m, 3H), 4.14–4.06 (m, 1H), 3.79 (s, 3H), 2.11 (s, 3H), 2.08 (s, 3H), 1.28–1.25 (m, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.6, 123.3, 122.6, 118.9, 118.1, 92.5, 70.0, 68.3, 63.3, 63.2, 51.8, 23.5, 22.1, 21.0, 20.9. HRMS (ESI): m/z Calcd for $C_{17}H_{23}NNaO_8$ $[M+Na]^+$: 392.1316, found 392.1319.

Methyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(cyclohexyloxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5s): Colorless syrup. [α]25 D = −12.8 (c 0.63, CH_2Cl_2). IR (neat) ν_{max} 3301, 3033, 2929, 1732, 1440, 1227, 1000, 735 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.21 (s, 1H), 6.84 (d, *J* = 3.0 Hz, 1H), 6.24 (dd, *J* = 5.3, 3.5 Hz, 1H), 5.82 (s, 1H), 4.30–4.25 (m, 3H), 3.81–3.73 (m, 4H), 2.11 (s, 3H), 2.08 (s, 3H), 1.98 (t, *J* = 12.7 Hz, 2H), 1.79–1.73 (m, 2H), 1.40–1.27 (m, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ **170.9**, 170.5, 160.5, 123.3, 122.6, 118.8, 118.2, 92.4, 76.0, 68.3, 63.4, 63.2, 51.8, 33.7, 32.2, 25.7, 24.6, 24.3, 21.0, 20.9. HRMS (ESI): m/z Calcd for $C_{20}H_{27}NNaO_8$ $[M+Na]^+$: 432.1629, found 432.1641.

Methyl (4S,6R,7R)-7-acetoxy-6-(acetoxymethyl)-4-(benzyloxy)-2,4,6,7-tetrahy-dropyrano [3,4-c]pyrrole-1-carboxylate (5t): White solid. [α]25 D = −20.8 (c 0.36, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.27 (s, 1H), 7.41–7.34 (m, 4H), 7.30 (ddd, *J* = 7.0, 3.8, 1.5 Hz, 1H), 6.88 (d, *J* = 3.1 Hz, 1H), 6.28 (d, *J* = 9.0 Hz, 1H), 5.78 (s, 1H), 4.86 (d, *J* = 11.8 Hz, 1H), 4.70 (d, *J* = 11.8 Hz, 1H), 4.27 (dq, *J* = 7.3, 5.7 Hz, 2H), 4.20 (d, *J* = 9.5 Hz, 1H), 3.79 (s, 3H), 2.11 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.9, 170.5, 160.5, 137.6, 128.6, 128.1, 128.0, 123.3, 121.9, 118.9, 118.5, 93.4, 69.8, 68.6, 63.1, 63.1, 51.9, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{21}H_{23}NNaO_8$ $[M+Na]^+$: 440.1316, found 440.1315.

Methyl (4S,6R,7R)-7-acetoxy-6-(acetoxymethyl)-4-methoxy-2,4,6,7-tetrahydro-pyrano[3,4-c]pyrrole-1-carboxylate (5u): White solid. [α]25 D = +28.0 (c 0.24, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.35 (s, 1H), 6.94 (d, *J* = 3.0 Hz, 1H), 6.26 (d, *J* = 2.0 Hz, 1H), 5.68 (s, 1H), 4.43 (ddd, *J* = 8.1, 3.8, 2.1 Hz, 1H), 4.36 (dd, *J* = 11.6, 4.0 Hz, 1H), 4.19 (dd, *J* = 11.6, 8.2 Hz, 1H), 3.81 (s, 3H), 3.51 (s, 3H), 2.11 (s, 3H), 2.07 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.8, 170.1, 160.8, 121.1, 121.1, 119.3, 118.7, 95.2, 68.2, 63.3, 61.7, 55.2, 51.8, 21.0, 21.0. HRMS (ESI): m/z Calcd for $C_{15}H_{19}NNaO_8$ $[M+Na]^+$: 364.1003, found 364.1000.

ethyl (4S,6R,7S)-7-acetoxy-6-(acetoxymethyl)-4-(benzyloxy)-2,4,6,7-tetrahydropyrano[3,4-c]pyrrole-1-carboxylate (5v): Colorless syrup. [α]25 D = −22.8 (c 2.16, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.33 (s, 1H), 7.40–7.33 (m, 4H), 7.32–7.27 (m, 1H), 6.86 (d, J = 3.0 Hz, 1H), 6.30–6.25 (m, 1H), 5.78 (s, 1H), 4.85 (d, J = 11.8 Hz, 1H), 4.69 (d, J = 11.8 Hz, 1H), 4.37–4.32 (m, 1H), 4.24 (dddd, J = 23.3, 14.2, 7.7, 4.5 Hz, 4H), 2.10 (s, 3H), 2.09 (s, 3H), 1.30 (t, J = 7.1 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.97, 170.55, 160.04, 137.73, 128.62, 128.15, 127.98, 123.11, 121.84, 119.23, 118.22, 93.47, 69.75, 68.85, 63.28, 63.20, 60.94, 21.10, 20.99, 14.54. HRMS (ESI): m/z Calcd for $C_{22}H_{25}NNaO_8$ $[M+Na]^+$: 454.1472, found 454.1479.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords: 2-nitroglycals · Ferrier rearrangement · Barton-Zard reaction · *N*-heterocyclic carbene · One-pot

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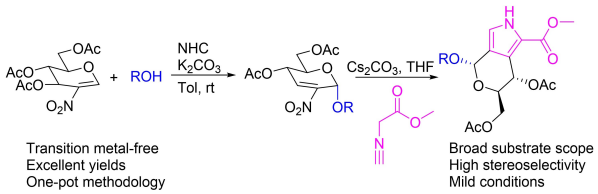

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Carbohydrate Chemistry: the first NHC-catalyzed stereoselective synthesis of 2-nitro-2,3- unsaturated glycosides under mild reaction conditions is reported. The synthesis of chiral pyrrole in one-pot is transition-metal-free and has a broad substrate scope with high yields and excellent stereoselective.