

PALLADIUM (II)-CATALYZED STEREOSELECTIVE
FORMATION OF α -*O*-GLYCOSIDES

by

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A thesis submitted in partial fulfillment
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ABBREVIATIONS

IgG	Immunoglobulin G
Ac	Acetyl
Cyc	Cyclopentane
<i>t</i> -Bu	<i>tert</i> -Butyl
Me	Methyl
TEA	Triethylamine
Ar	Aryl
Tr	Trityl
TBS	<i>tert</i> -Butylsilane
Imid.	Imidazole
py	Pyridine
DTTBP	2-Di- <i>t</i> -butylphosphino-2',4',6'-tri- <i>i</i> -propyl-1,1'-biphenyl
JohnPhos	2-(Di- <i>t</i> -butylphosphino)biphenyl
RuPhos	2-Dicyclohexylphosphino-2',6'-di- <i>i</i> -propoxy-1,1'-biphenyl
X-Phos	2-(Dicyclohexylphosphino)-2',4',6'-tri- <i>i</i> -propyl 1,1'-biphenyl
<i>i</i> -Pr	Isopropyl
L _n	Ligand
Bz	Benzoyl
Piv	Pivaloyl
LG	Leaving Group
R or R ¹	Alkyl Group

ABBREVIATIONS-CONTINUED

Et	Ethyl
Bu	<i>n</i> -Butyl
Cp	Cyclopentadiene
M	Metal
TMS	Trimethylsilane
DAST	Diethylaminosulfur Trifluoride
DBU	1,8-Diazabicyclo[5.4.0]undec-7-ene
Ph	Phenyl
Tf	Trifluoromethanesulfonyl
dba	Dibenzylidene Acetone
THF	Tetrahydrofuran
Tol	Toluene
DCM	Dichloromethane
NMR	Nuclear Magnetic Resonance
DDQ	2,3-Dichloro-5,6-dicyano-1,4-benzoquinone
DMF	N,N'-Dimethylformamide
TBAF	Tetrabutylammonium Fluoride
r.t.	Room Temperature
IR	Infrared
Bn	Benzyl

ABSTRACT

The development of new methods for stereoselective formation of α - or β -*O*-glycosides has been extensively investigated due to the critical roles carbohydrates play in a variety of biological systems. To date, many efforts have focused on developing new methods and reagents for the generation of isolated glycosyl donors which subsequently undergo glycosidic bond formation with nucleophilic glycosyl acceptors. Despite their potential applications to complex carbohydrate synthesis, each of these methods relies on the nature of the substrates to stereoselectively control the formation of glycosidic bonds. Recently, the use of glycal derivatives as glycosyl donors has been utilized in π -allylpalladium strategies for the stereoselective synthesis of *O*-glycosides. However, due to the poor reactivity of the glycal donors as well as the alcohol nucleophiles, these groups utilized the more activated pyranone donors. Lee, who recognized the challenge in this approach, utilized Zn(II) ion to activate both the alcohol acceptors for the nucleophilic addition and the glycal donors for the ionization.

My research focuses on the development of a novel method for the stereoselective construction of α -*O*-glycosides directly from glycals. In this reaction, the Pd(II)/L catalyst is believed to activate the glycal π -system for stereoselective attack by the oxygen nucleophile, and the C(3)-trichloroacetimidate group serves as the leaving group as well as directs Pd(II) to the double bond of the glycal. This strategy relies on palladium-ligand catalyst-donor complexation to control the anomeric selectivity rather than the nature of the protecting groups on the substrates, thus eliminating the need for cumbersome protecting group manipulations that are often employed in glycosylation. The α - selectivity relies on the reagent rather than on the nature of the substrates, which is often employed in traditional glycosylation. This mild method is applicable to an array of glycal donors and aliphatic and aryl alcohol acceptors. The advantages of this methodology are the mild conditions, low reaction temperatures, short reaction times, scope of glycosyl acceptors and donors it applies to, and minimal catalytic loading. Furthermore these reactions are generally express high yield and selectivity.

INTRODUCTION

Carbohydrates are the most highly diverse class of biomolecules in nature. It is well known that carbohydrates play a vast array of roles in biological processes;¹ some of these roles include cell – cell recognition,² cellular transport,³ metabolism,⁴ storage and transport of energy,⁵ functioning of the immune system,⁶ fertilization,⁷ pathogenesis,⁸ blood clotting,⁹ and adhesion.¹⁰ The addition of saccharides to proteins or lipids, known as glycosylation, is a major posttranslational modification of membranes and secreted proteins in cells.¹¹ Alterations in the structures of glycans and polysaccharides are associated with a variety of diseases, including metastatic cancer. Investigation into carbohydrates has increased over recent years due to their importance as building blocks,¹² biological tools,¹³ potential drug candidates,¹⁴ and synthetic targets.¹⁵ For example, Boons and coworkers have successfully synthesized the first three-component synthetic carbohydrate anticancer vaccine and have demonstrated that it elicits an immune response through IgG antibodies (Figure 1.1).¹⁶

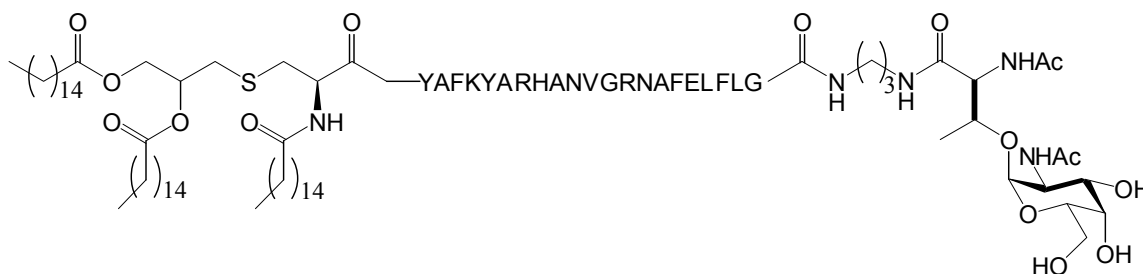


Figure 1.1

Mannopeptimycins, newly discovered class of glycopeptides antibiotics produced by *streptomyces hygroscopicus* LL-AC98, have shown antibacterial and mechanistic activities (Figure 1.2).¹⁷ Therefore, a glycosylation methodology to stereoselectively construct cyclic glycopeptides is of synthetic interest.

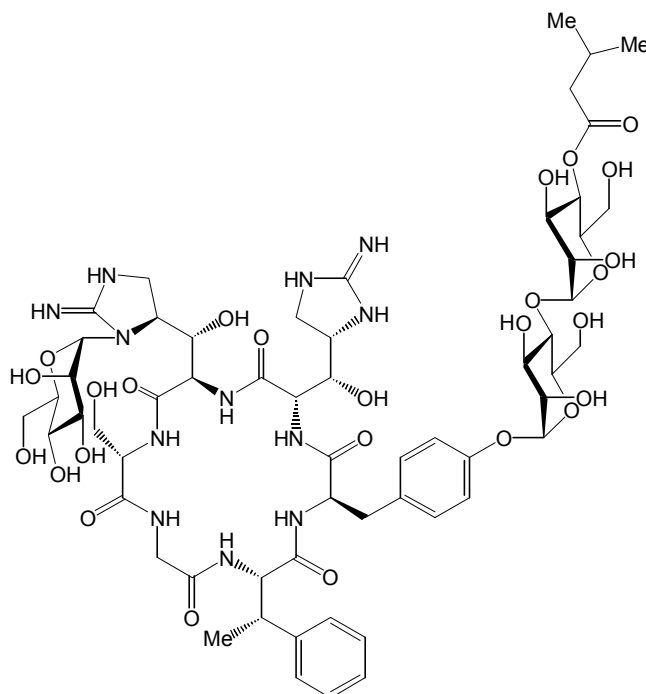
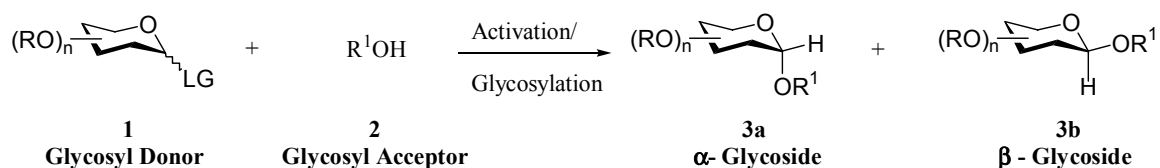


Figure 1.2

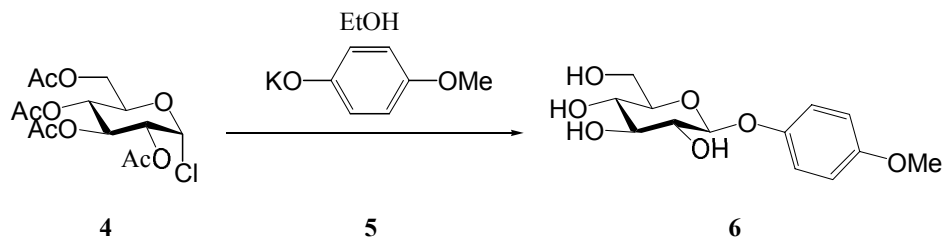
A variety of glycosylation methods have been developed for complex carbohydrate synthesis due to the critical role carbohydrates play in metabolic pathways.¹⁸ In forming glycosidic bonds, the glycosyl donor and the glycosyl acceptor are the two required components; a glycosyl donor **1** is referred to as the carbohydrate unit that donates its anomeric center to the glycosidic bond, and a glycosyl acceptor **2** is

referred to as the unit that receives the anomeric center (Scheme 1.1). In general, a promoter or catalyst is needed to activate the electrophilic glycosyl donor's anomeric leaving group that then is coupled with an appropriate nucleophilic glycosyl acceptor to generate a glycoside **3** as a mixture of α and β anomers.



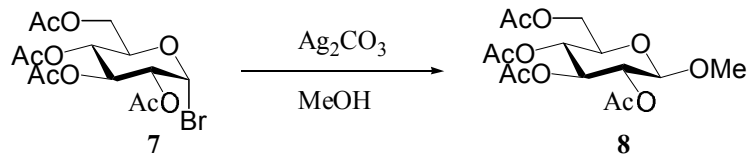
Scheme 1.1

In 1879, the first synthesis of a glycosidic bond was reported by Michael.¹⁹ In the reaction, treatment of 2,3,4,6-tetra-*O*-acetyl- α -D-glucopyranosyl chloride **4** with the potassium salt of 4-methoxyphenol **5**, in absolute ethanol, provided β -D-*O*-phenyl glycoside **6** (Scheme 1.2). Unfortunately, this procedure could only be applied to the synthesis of aryl glycosides and the acetyls were easily hydrolyzed.



Scheme 1.2

In 1901, Koenigs and Knorr reported that the treatment of 2,3,4,6-tetra-*O*-acetyl- α -D-glucopyranosyl bromide **7** with silver carbonate, in the presence of methanol, provided β -D-*O*-methyl glycoside **8** (Scheme 1.3).²⁰



Scheme 1.3

The stereochemical outcome of this reaction is influenced by the presence of the neighboring group at the C(2)-position, that via anchimeric assistance provides the formation of a 1,2-*trans* stereochemical arrangement (Figure 1.3). In general, esters provide good neighboring group participation whereas ethers do not, leading to a mixture of stereoisomers.

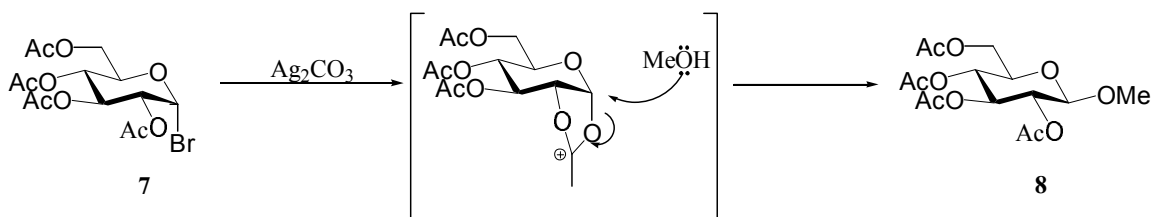
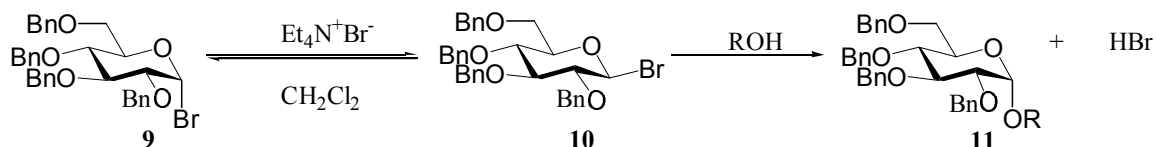


Figure 1.3

Several disadvantages exist in the Koenigs – Knorr glycosylations. First, the unstable glycosyl halides are prepared using harsh reaction conditions. In addition, the toxic and sometimes explosive coactivators are generally used in equimolar quantities. Furthermore, glycosyl halides are prone to undergo 1,2-elimination or hydrolysis.

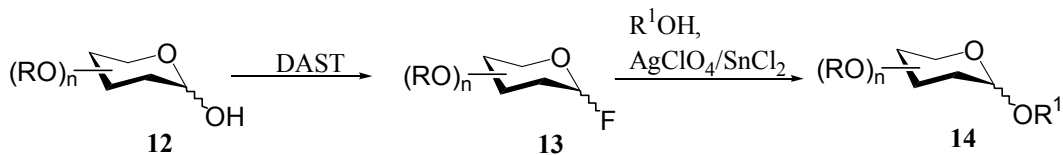
Lemieux and coworkers introduced a mild glycosylation method that eliminated the use of stoichiometric amounts of heavy metals (Scheme 1.4).²¹ Lemieux's method utilized glycosyl bromide **9** or chloride in the presence of a phase transfer catalyst such as

Bu₄N-Br to yield the corresponding glycoside **11**. This methodology led to the elegant syntheses of several blood group antigenic determinants.²²



Scheme 1.4

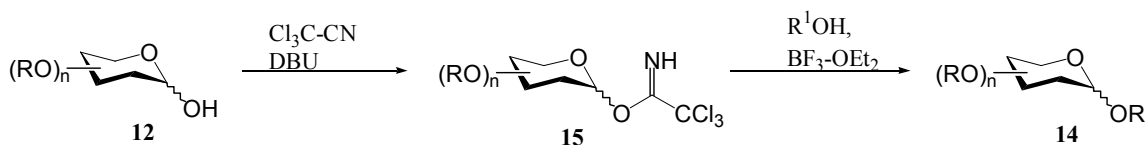
In 1981, Mukaiyama and coworkers introduced a method closely related to the Koenigs – Knorr glycosylation where a considerably more chemically stable glycosyl fluoride donor **13** is utilized in place of its glycosyl bromide and chloride counterparts (Scheme 1.5).²³ A major advantage of this methodology is the ease of preparation of the glycosyl fluoride donors; these donors are prepared under mild conditions from the corresponding hemiacetal **12** via the use of diethylaminosulfur trifluoride (DAST). Due to the synthetic flexibility of glycosyl fluorides, a diversity of fluorophilic activating reagents have been found to promote glycosylation, including SiF₄, TMSOTf, BF₃-OEt₂, and AgClO₄/[CpMCl₂] (M = Zr or Hf).²⁴



Scheme 1.5

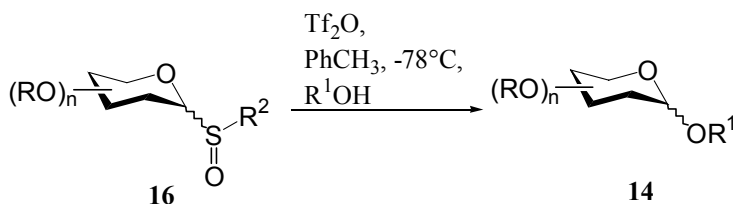
In 1980, Schmidt and coworkers developed a trichloroacetimidate-mediated glycosylation method that has proven to be of high synthetic value in the construction of

complex molecules (Scheme 1.6).²⁵ The activated derivative is easily prepared in comparison to traditional methods. In the presence of a base such as DBU or NaH, treatment of a hemiacetal **12** with trichloroacetonitrile yields the corresponding trichloroacetimidate lactal donor **15**. In general, the trichloroacetimidate glycosyl donor is activated via a Lewis acid such as TMSOTf or $\text{BF}_3\text{-OEt}_2$.



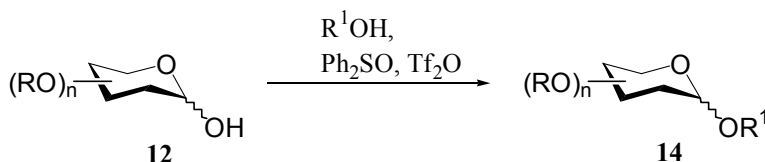
Scheme 1.6

Kahne and coworkers have reported the use of sulfoxides as effective latent leaving groups. In the reaction, glycosyl sulfoxides **17** were activated with trifluoromethanesulfonic anhydride in toluene at $-78\text{ }^\circ\text{C}$ and subsequently coupled with a glycosyl acceptor to yield glycoside **18** (Scheme 1.7).²⁶ The Kahne method proves to be efficient in the preparation of glycosides from sterically hindered or otherwise unreactive substrates. Unfortunately, the stereochemical outcome of the coupling is dependent on the glycosyl donor and glycosyl acceptor protecting groups. This method goes through a glycosyl triflate generated upon reacting the sulfoxide with triflate anhydride at $-78\text{ }^\circ\text{C}$ in toluene.



Scheme 1.7

In 1997, Gin and coworkers developed an efficient one-pot dehydrative glycosylation method that utilizes the combination of Ph_2O and Tf_2O as activating agents for the construction of the glycosidic bond directly from the C(1)-hemiacetal **12** (Scheme 1.8).²⁷



Scheme 1.8

The use of glycal derivatives as glycosyl donors has recently been used in π -allylpalladium strategies for the stereoselective synthesis of *O*-glycosides.^{31,32b,33} Of current synthetic interest is mannopeptimycin E due to the notable increasing bacterial resistance to antibiotics.²⁸ Manno-peptimycin E is the most reactive of the manno-peptimycins. So far, Wang and coworkers have successfully reported a route to construct a cyclic peptide core related to manno-peptimycin possessing a C(4)/C(6) acetal as an isovalerate substitute.²⁹ Based on Wang's work, O'Doherty and coworkers approached the synthesis of an *O*-glycosylated D-tyrosine containing the C(4) isovalerate substitution (Figure 1.4).³⁰ O'Doherty applies a palladium-glycosylation strategy that provides a diastereoselective route yielding the *manno*-disaccharide fragments of manno-peptimycin-E from D-tyrosine. However, as seen with previous glycosylation methodology, O'Doherty's strategy is substrate dependent thus relies heavily on protecting group manipulations.

8

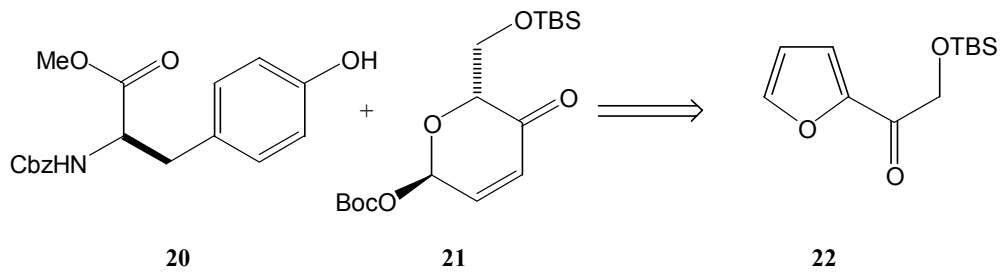
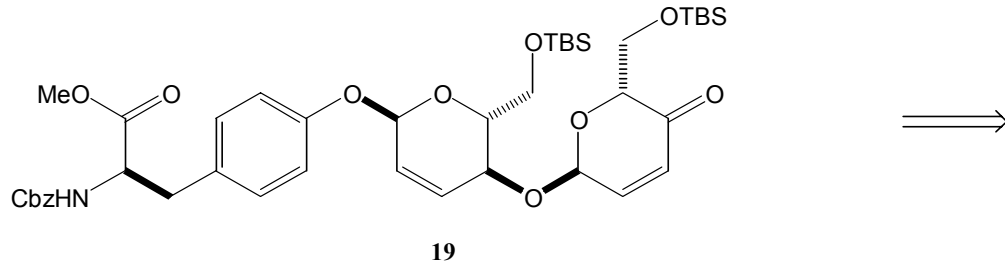
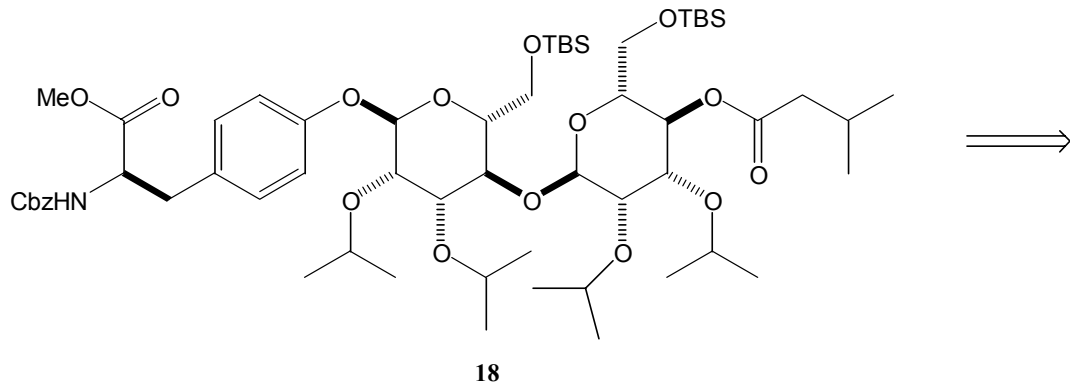
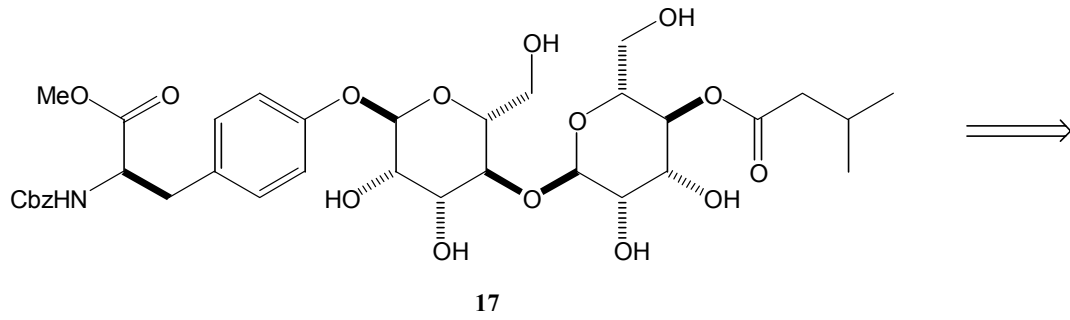
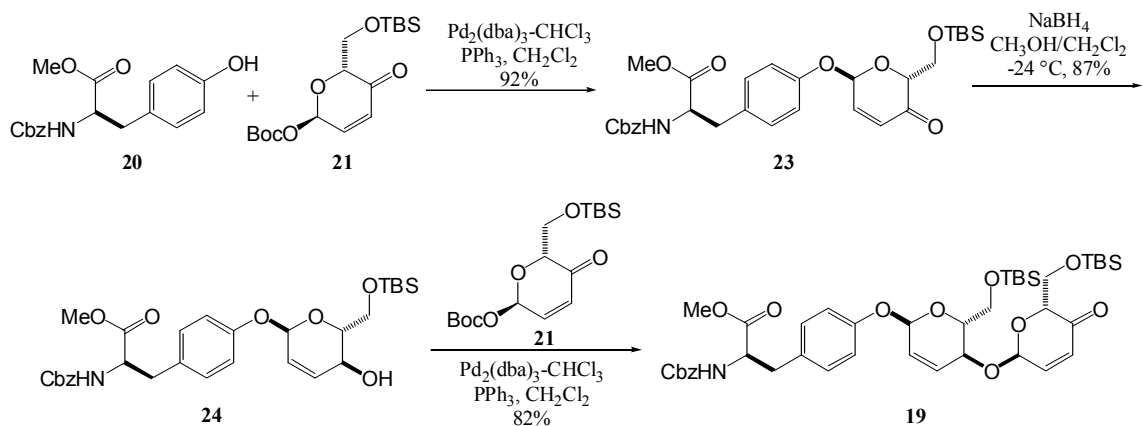


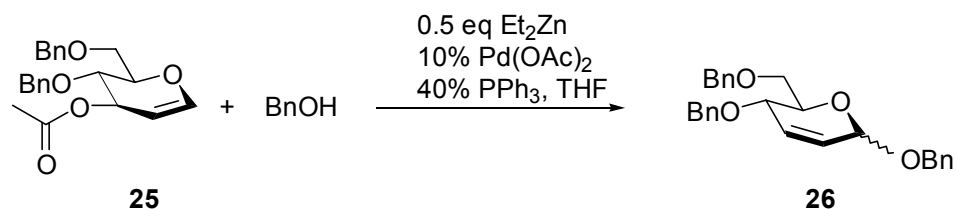
Figure 1.4

O' Doherty's strategy is dependent on a *de novo* π -allylpalladium based glycosylation that utilizes the highly reactive pyranones as glycosyl donors (Scheme 1.9).³¹ Some advantages to this palladium based strategy are that the glycosylation proceeds with high diastereoselectivity, the palladium is used in catalytic amounts, and the reaction conditions are mild in the sense that the use of a stoichiometric amount of Lewis acid promoter is avoided. However, due to the poor reactivity of the glycal donors as well as the alcohol nucleophiles, this π -allylpalladium glycosylation strategy is limited to the relatively more activated pyranone donors.³²



Scheme 1.9

Lee and coworkers were able to increase the reactivity by utilizing the Zn(II) ion to activate both the alcohol acceptors for the nucleophilic addition and the glycal donors for the ionization (Scheme 1.10).³³ A major disadvantage to Lee's approach is lengthened reaction times.



Scheme 1.10

Currently, many efforts are being concentrated on developing new methodologies and reagents for the construction of isolated glycosyl donors which react with nucleophilic glycosyl acceptors to form glycosidic bonds.³⁴ In all of these methods, the stereoselective control of the glycosidic bond is dependent on the nature of the substrate. Often, burdensome protecting group manipulations on the substrate are required in glycosylation reactions to control the anomeric selectivity, resulting in the addition of multiple synthetic steps and decreased yields. Therefore, the development of a methodology that does not rely on protecting groups for anomeric selectivity is needed. This thesis will present my efforts to develop such a methodology that utilizes mild palladium catalyzed reaction conditions.

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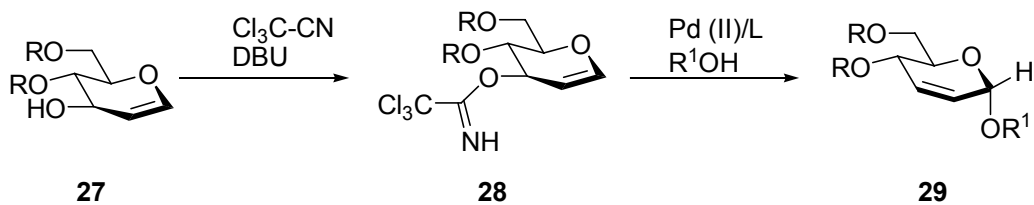
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PALLADIUM (II)-CATALYZED STEREOSELECTIVE
FORMATION OF α -*O*-GLYCOSIDES

Introduction

A novel method for the stereoselective construction of α -*O*-glycosides has been developed utilizing glycals as glycosyl donors. The α -*O*-glycosides can be directly derived from glycals through the use of a Pd(II)/ligand catalyst, which is further described in this chapter. In this reaction, it is believed that the glycal π system of **28** is activated by the Pd(II)/ligand complex for the stereoselective attack by the external oxygen nucleophile. The trichloroacetimidate group functions as the leaving group as well as the directing group for the Pd(II) catalyst to the double bond of glycal **28** (Scheme 2.1).

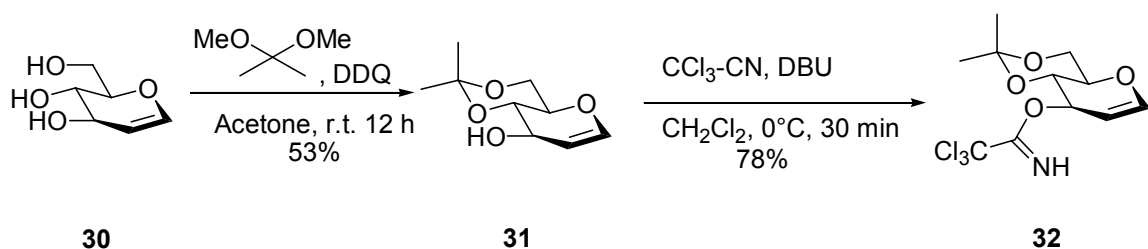


Scheme 2.1

One of the major advantages to this strategy is that the anomeric control relies on palladium-ligand catalyst-donor complexation instead of the nature of the protecting groups on the substrates. This eliminates tedious protecting group manipulations that are often associated with glycosylations.

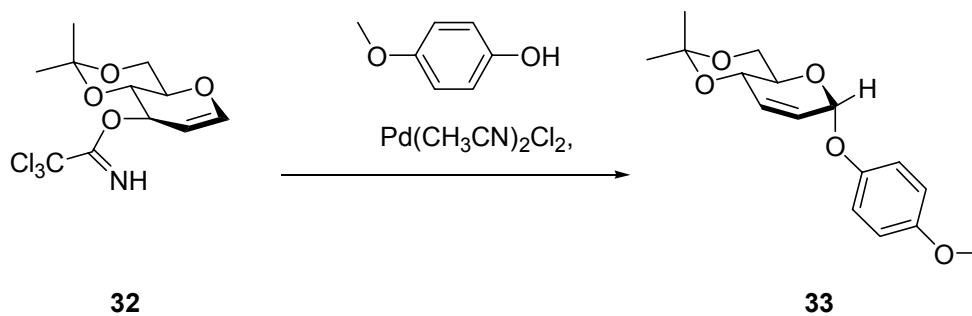
Initial Studies

Initial studies focused on optimizing reaction conditions utilizing the glucal imidate **32** which was prepared in two steps from D-glucal **30** (Scheme 2.2).¹ D-glucal **30** was treated with 2,2-dimethoxypropane and DDQ in acetone to yield the 1-hydroxyl sugar **31**. Subsequently, the thermally and chemically stable trichloroacetimidate glycosyl donor **32** was synthesized from the corresponding 1-hydroxyl sugar **31** by treatment with trichloroacetonitrile in the presence of DBU.



Scheme 2.2

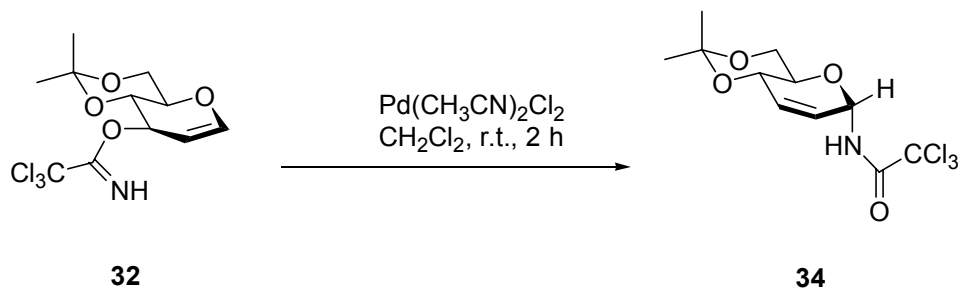
With access to glycal imidate **32**, efforts then focused on the feasibility of Pd(II)-catalyzed stereoselective formation of α -*O*-aryl glycosides. Initially, treatment of glucal imidate **32** with 5 mol % Pd(CH₃CN)₂Cl₂, 2.0 equivalents of *p*-methoxyphenol, and CH₂Cl₂ at 25 °C for 35 min provided glycoside **33** in 45% yield with α : β = 2:1 along with significant amount of decomposition (Table 2.1, entry 1). Decreasing the amount of the Pd loading to 2.5 mol % still afforded the product **33** in 46% yield with α : β = 4:1 (Table 2.1, entry 2). Changing the solvent from CH₂Cl₂ to toluene slowed down the reaction. The desired product **33** was obtained in 43% yield with α : β = 2:1 along with a significant amount of the undesired product (Table 2.1, entry 3).



Entry	$\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$	Solvent	Yield ($\alpha:\beta$)
1	5.0 mol %	CH_2Cl_2	45% (2:1)
2	2.5 mol %	CH_2Cl_2	46% (4:1)
3	2.5 mol %	Toluene	43% (2:1)

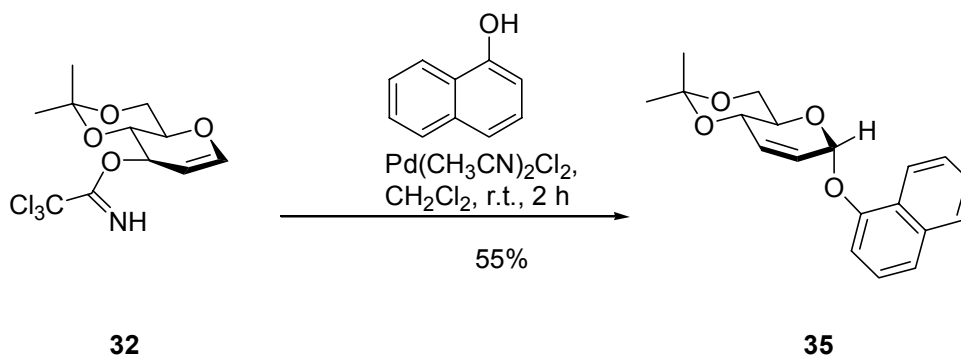
Table 2.1

The undesired product obtained with toluene as the solvent (Table 2.1, entry 3) is believed to be the glycosylamide **34**, which was formed via the allylic imidate rearrangement (Scheme 2.3).² In order to minimize the occurrence of **34**, CH_2Cl_2 was used as the reaction solvent for the rest of the glycosylation reactions.



Scheme 2.3

The next aryl alcohol nucleophile examined was the sterically hindered 1-naphthol. Under the optimized reaction conditions for *p*-methoxyphenol, glycoside **35** was obtained in 55% yield with $\alpha:\beta = 3:1$ (Scheme 2.4).



Scheme 2.4

It was hypothesized that the anomeric selectivity could be dependent of the palladium ligand. Accordingly, an assortment of Buchwald's sterically bulky biaryl phosphine ligands were screened (Table 2.2).

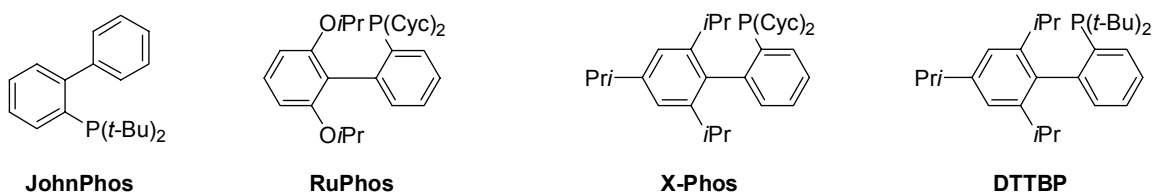
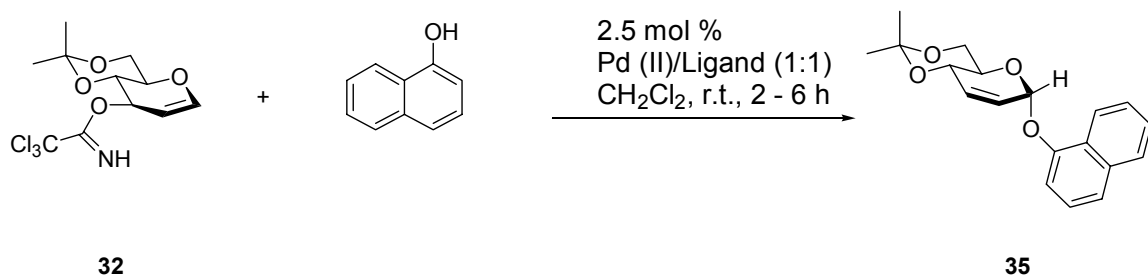


Table 2.2

Treatment of glucal imidate **32** with a preformed mixture of $\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$ with JohnPhos ligand in a 1:1 ratio has no effect on the outcome of the reaction. It is likely that the palladium/phosphine complex may not be in the reaction, since it is known that the rate of ligand exchange for $\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$ is slow.³ A significant improvement in yield occurred when $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ was used in place of $\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$. Furthermore, the anomeric selectivity slightly increased from $\alpha:\beta = 3:1$ to $\alpha:\beta = 4:1$.

After screening several of Buchwald's bulky biaryl phosphine ligands with Pd(PhCN)₂Cl₂ (Table 2.3), it was found that DTTBP provided glycoside **35** in good yield with excellent selectivity (Table 2.3, entry 5).



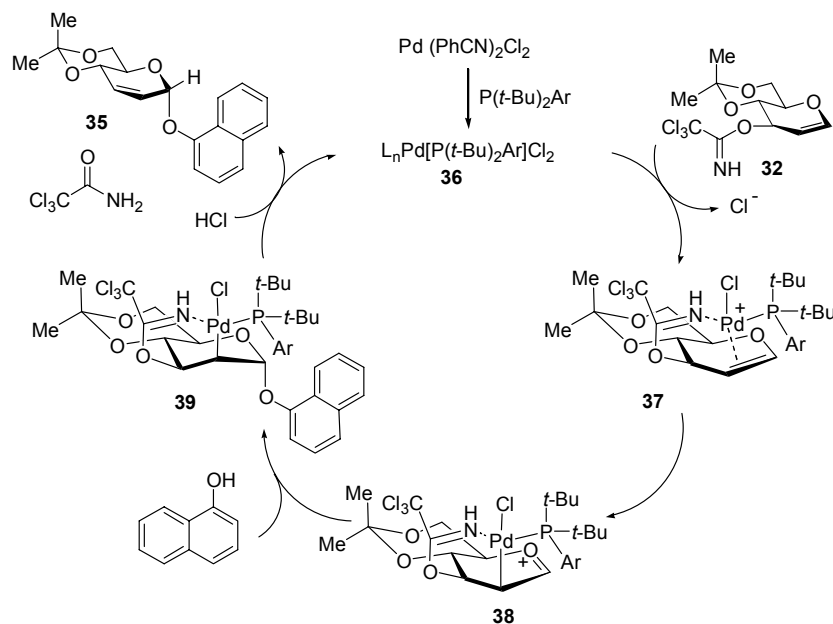
Entry	Pd (II) Sources	Phosphine Ligands	Yield	α:β
1	Pd(CH ₃ CN) ₂ Cl ₂	JohnPhos	53%	3:1
2	Pd(PhCN) ₂ Cl ₂	JohnPhos	91%	4:1
3	Pd(PhCN) ₂ Cl ₂	RuPhos	54%	4:1
4	Pd(PhCN) ₂ Cl ₂	X-Phos	70%	8:1
5	Pd(PhCN) ₂ Cl ₂	DTTBP	84%	20:1

Table 2.3

All reactions were carried out with a concentration of 0.2 M, 2.0 equivalents of 1-naphthol, 2.5 mol % phosphine, and 2.5 mol % Pd (II) in CH₂Cl₂. These results suggest that a more bulky biaryl phosphine ligand increases the yield and anomeric selectivity of the reaction.

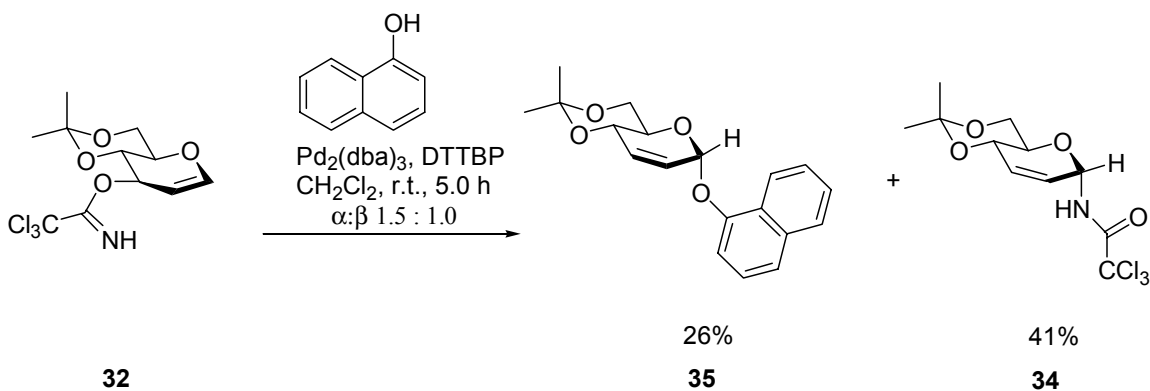
Proposed Mechanism

A proposed mechanism for the Pd(II)-catalyzed stereoselective formation of *O*-glycosides is shown in Scheme 2.5. Ligand exchange between Pd(PhCN)₂Cl₂ and DTTBP occurs to yield the palladium/phosphine complex **36** which then undergoes reversible coordination to both imidate's nitrogen and olefin of the glucal **32** to form the palladium-olefin complex **37**. Subsequent migratory insertion will provide the oxonium palladium-σ complex **38**. Nucleophilic attack by the glycosyl acceptor on the β face of **38** is sterically blocked by the bulky biaryl phosphine ligand. As a result, 1-naphthol approaches to the α face leading to the glycoside intermediate **39**. Deoxypalladation of **39** and subsequent dissociation yields the glycoside **35**. In this catalytic cycle, 1-naphthol acts as both the nucleophile and the proton donor.



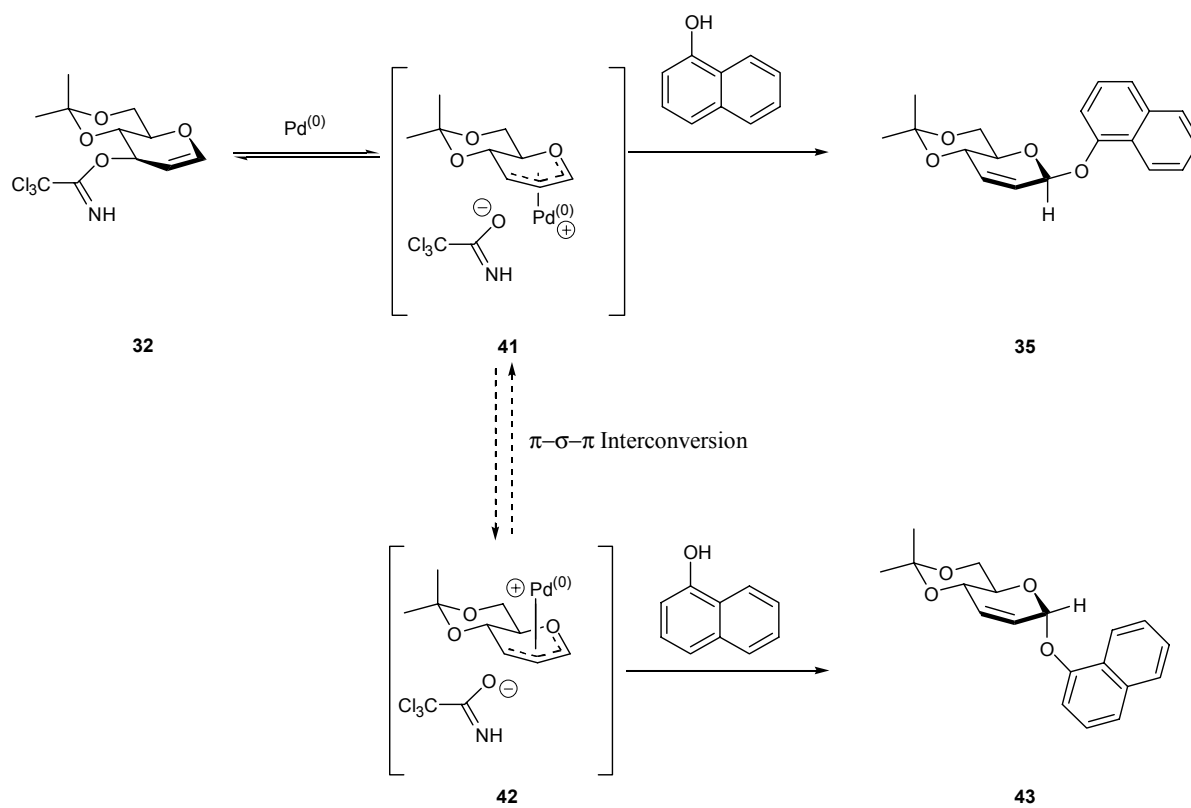
Scheme 2.5

In order to make sure that this reaction does not undergo a π -allylpalladium mechanism, a control experiment was performed (Scheme 2.6). The major concern was that the electron-rich phosphine would reduce Pd(II) to Pd⁰. The glucal imidate **32** was treated with a preformed solution of 2.5 mol % Pd₂(dba)₃ and DTTBP in the presence of 2 equiv of 1-naphthol to yield glycoside **35** in 26% yield with α : β = 1.5:1. The major product was the [3.3]-sigmatropic rearrangement product **34** which was obtained in 41% yield.



Scheme 2.6

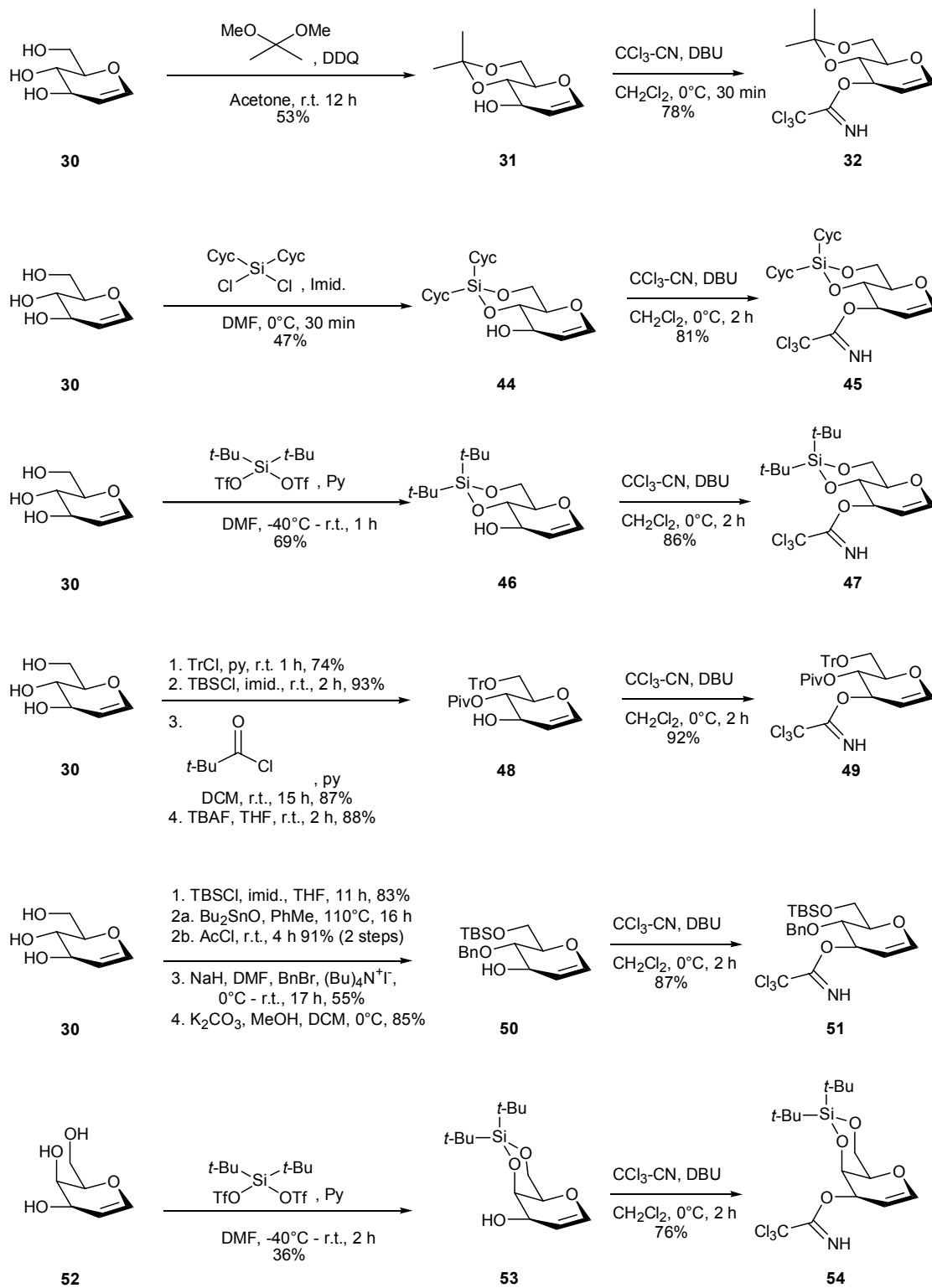
Had the mechanism gone through a π -allylpalladium intermediate, there would have been no control of stereochemistry and a racemic mixture of α and β anomers would have been observed (Scheme 2.7).⁴ Our primary concern was that the electron rich phosphine was reducing our palladium source from palladium (II) to palladium (0). However, our results were showed that clearly our mechanism did not proceed through a π -allylpalladium mechanism.



Scheme 2.7

Pd(II)-Catalyzed Stereoselective Formation of *O*-Aryl Glycosides

To test the feasibility of this novel palladium-catalyzed stereoselective methodology in terms of *O*-aryl glycoside synthesis, several glucal and galactal donors (Scheme 2.8) with a variety of protecting groups were synthesized.



Scheme 2.8

With the glycal imidates **32**, **45**, **47**, **49**, **51**, and **54** in hand, the palladium(II) catalyzed stereoselective formation of α -*O*-glycosides was investigated with an array of aryl alcohols (Table 2.4).

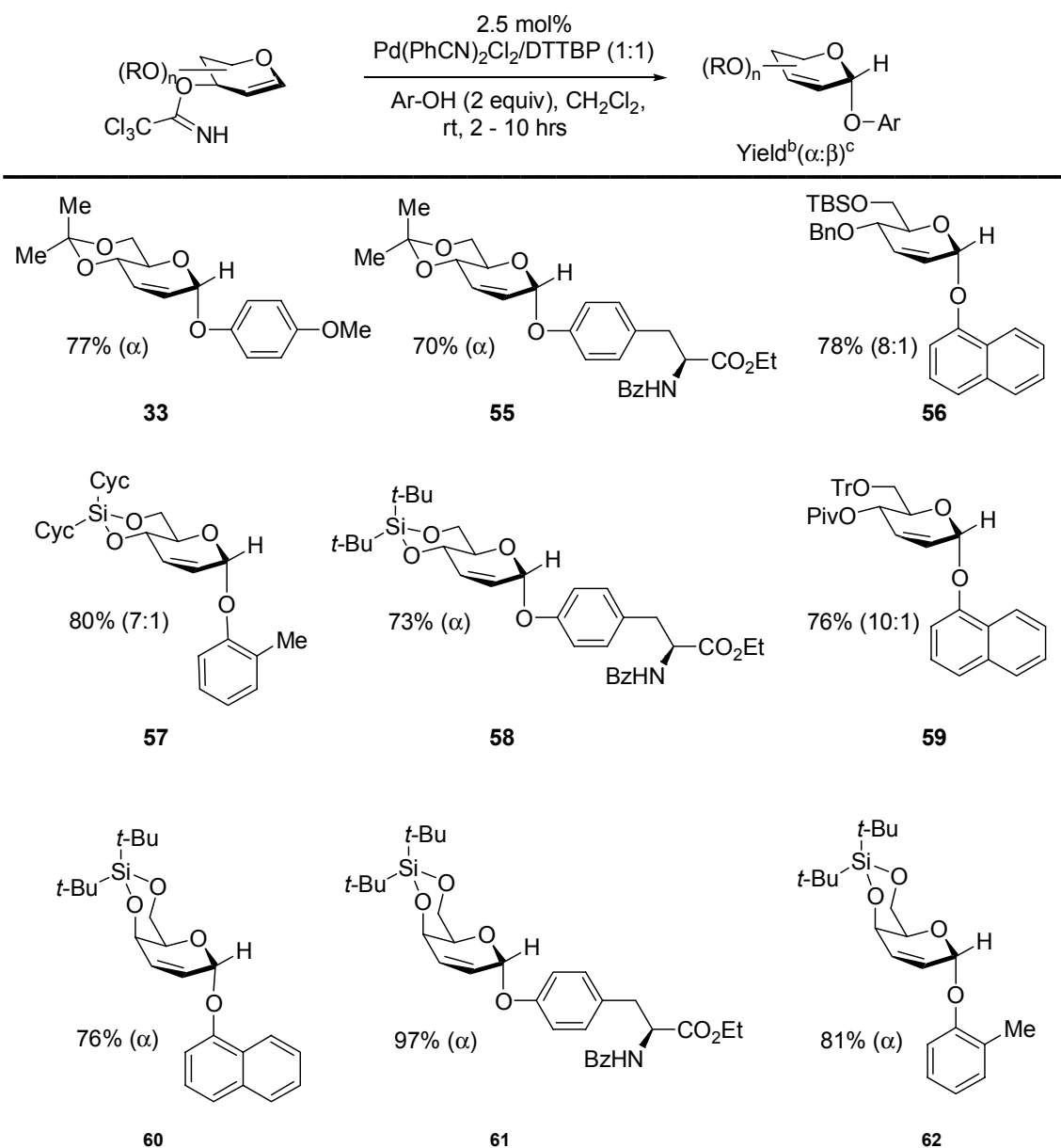
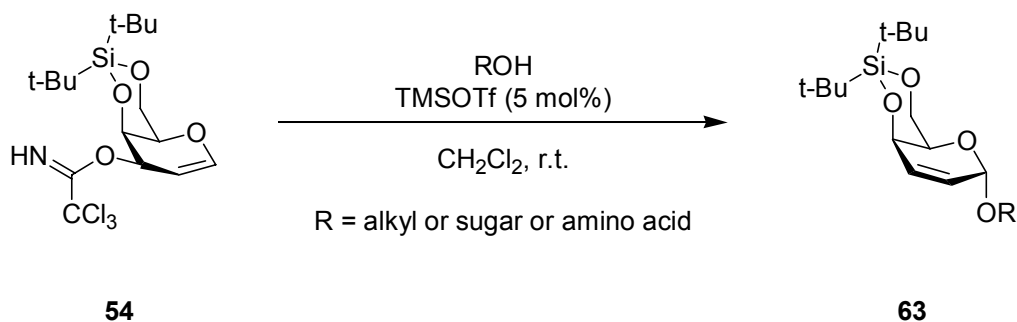


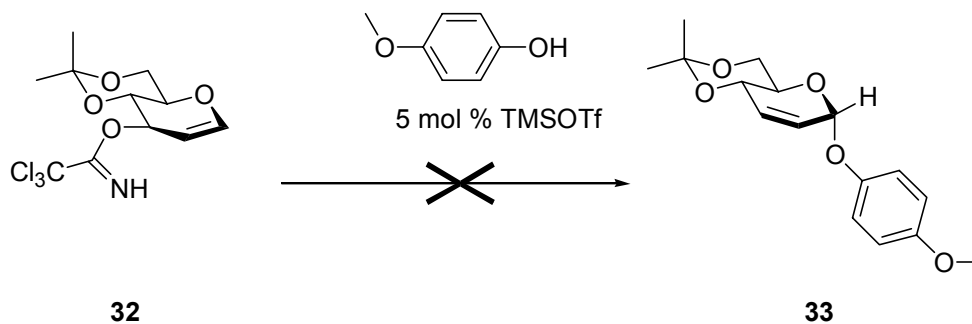
Table 2.4

The desired glycosides **33**, **55-62** were obtained in good yield with excellent anomeric selectivity. From the results, it can be concluded that the bulky biaryl phosphine ligands were responsible for the anomeric stereoselectivity. This implies that the protecting groups have no influence on the stereochemical outcome and this methodology is reagent based opposed to substrate based. Schmidt and coworkers have reported utilizing galactal imidates **54** as glycosyl donors to obtain exclusively α -*O*-glycosides **63** (Scheme 2.9).⁵



Scheme 2.9

It is important to note that the α -selectivity is due to increased steric hindrance obtained from the axial C(4)-OH. These conditions are limited to using galactal imidates and aliphatic alcohols. Repeating Schmidt's conditions with glucal imidate **32** with 5 mol % of TMSOTf in the presence of 2 equiv of 1-naphthol only led to decomposition (Scheme 2.10).



Scheme 2.10

Pd(II)-Catalyzed Stereoselective Formation of *O*-Glycosides

Extending this methodology to form *O*-glycosides from aliphatic alcohols was then investigated. Due to the poor nucleophilicity of benzyl alcohol, it was initially converted to the relatively reactive potassium alkoxides (Table 2.5, entry 1). The glycoside **64** was obtained in 21% exclusively as the α -anomer along with the recovery of galactal imidate **54** in 53% yield. Next, benzyl alcohol was converted to the relatively more reactive zinc (II) alkoxide.⁶ Accordingly, treatment of galactal imidate **54** with a preformed solution of BnOH (3.0 equiv) and ZnEt₂ (1.5 equiv) and 2.5 mol % Pd(PhCN)₂Cl₂/DTTBP in a mixture of toluene and CH₂Cl₂ (1:2) provided glycoside **64** in 68% yield along with the rearrangement product **65** in 22% yield (Table 2.5, entry 2). In this reaction, 2,6-di-*t*-butylphenol was used as the proton donor in order for the palladium/phosphine catalyst to turn over. Decreasing the amount of benzyl alcohol significantly increased the yield of the glycoside **64** to 77% (Table 2.5, entry 3).

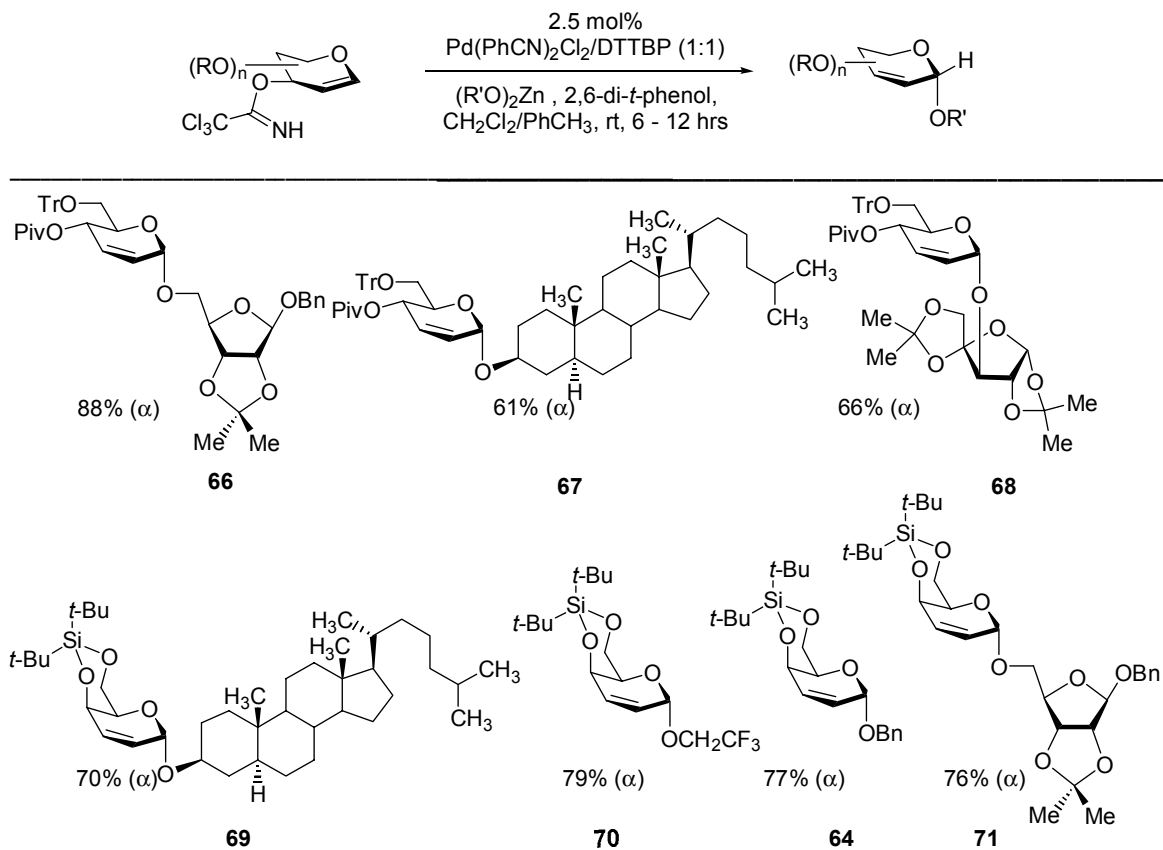


Table 2.6

By inspecting the NMR data, it was determined that the major byproduct in these glycosylations was the [3.3]-sigmatropic rearrangement product. It is believed that the zinc promoted the rearrangement. The scope of this method was extended into primary and secondary hydroxyls of carbohydrate nucleophiles. The desired glycosides **64**, **66-71** were isolated in good yield and exclusively as the α -anomers.

Conclusions

Using glycols as starting material, a novel method for the stereoselective construction of α -*O*-glycosides has been developed. The scope of this methodology can be applied to both aryl and aliphatic alcohols as glycosyl acceptors. For the reaction to proceed with aliphatic alcohols, the glycosyl acceptor needed to be “softened” by converting them to the corresponding zinc alkoxide. The trichloroacetimidate of the glycosyl donor serves as both the leaving group and directs the coordination of the palladium-phosphine complex to the glucal π -system. As a result, the palladium-phosphine complex sterically blocks the β -face of the glycosyl donor from nucleophilic attack resulting in predominately the alpha anomer. In the case of galactals, strictly α -anomer is observed due to the axial hydroxyl at the C(4)-position. This approach proceeds via mild glycosylation conditions with shortened reaction times at room temperature. In addition, the anomeric stereoselectivity is reagent based as opposed to traditional substrate based glycosylations where tedious protecting group manipulations are often employed.

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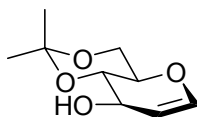
EXPERIMENTALS

General Experimental

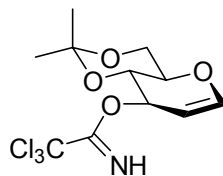
All experiments were carried out under a positive pressure atmosphere of dry argon gas using oven-dried (140 °C, >24 hours) Schlenk flasks fitted with glass stoppers. Organic solutions were concentrated by rotary evaporation below 40°C at 25 torr. Analytical thin-layer chromatography (TLC) was performed on Sorbent Silica XHL TLC plates, w/ UV254, glass backed, 0.25 mm, 20 x 20 cm plates. Visualization was achieved using UV-light, iodine, cerium molybdate, or potassium permanganate. Column chromatography was performed on Silicycle Ultrapure 60 Å 230-400 mesh silica gel. Solvents for column chromatography and TLC are reported in volume/volume mixtures and are reagent grade. Methylene chloride (DCM), tetrahydrofuran (THF), and toluene were distilled from calcium hydride under an argon atmosphere at 760 torr and stored over 4 Å sieves. Triethylamine (TEA) was distilled from and stored over KOH. Buchwald's biaryl phosphine ligands, Pd(CH₃CN)₂Cl₂ and Pd(PhCN)₂Cl₂ were purchased from Strem Chemicals. Ribose was provided by the Cloninger Laboratory located at Montana State University. All other chemicals were obtained from commercial vendors and used without further purification.

All proton (^1H) and carbon (^{13}C) nuclear magnetic resonance spectra were recorded on a Bruker 300 (300 MHz and 75 MHz) or Bruker 500 (500 MHz and 125 MHz) NMR spectrometer. For ^1H and ^{13}C spectra, all chemical shifts were reported in parts-per-million (ppm) downfield from tetramethylsilane with residual hydrogen bearing solvent resonance as the internal standard. (deuteriochloroform (CDCl_3): 7.26 ppm for proton and 77.23 ppm for carbon). Furthermore, all ^{13}C spectra are proton decoupled. NMR data is reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, pent = pentet, m = multiplet; addition of b indicates a broadened splitting pattern), coupling constant in hertz (Hz), and integration. Infrared spectra were recorded on a JASCO FT/IR-4100 as dichloromethane films on sodium chloride cell plates and absorption frequencies are reported in cm^{-1} (w = weak intensity, m = medium intensity, s = strong intensity, vs = very strong intensity, b = broad absorption). High resolution (ESI) mass spectrometric data was obtained on a Bruker Mircotof (ESI-TOF) spectrometer at the mass spectrometry laboratory located at Montana State University.

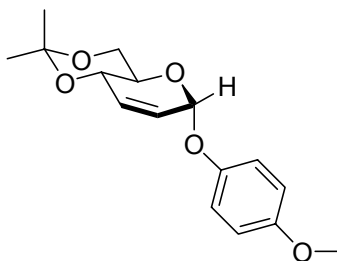
Melting points were taken on Lab Device Mel-Temp. Spectral and physical properties for all isolated compounds made from literature preparations are consistent with the values reported.

Experimentals**31**

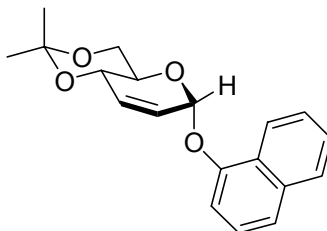
Compound (**31**) [BS-I-90]. An oven-dried 50 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with D-glucal (800 mg, 5.47 mmol, 1.0 equiv) and dry acetone (24.0 mL, 328.45 mmol, 60.0 equiv). Once the D-glucal was fully dissolved, 2,2-dimethoxypropane (2.0 mL, 16.42 mmol, 3.0 equiv) was added followed by DDQ (62.1 mg, 0.27 mmol, 0.05 equiv). The reaction mixture was allowed to stir at room temperature for 23 h before being diluted with 80.0 mL of ethyl acetate. The resulting solution was washed with 80.0 mL of NaHCO₃ (sat.) and the organic layer was extracted. The aqueous layer was back extracted with 40.0 mL of ethyl acetate twice. The organic layers were combined and dried over MgSO₄, filtered, and concentrated in vacuo. The resulting crude product was purified by silica gel flash chromatography (2/1. hexane/ethyl acetate) to yield **31** (0.54 g, 53 %). IR (film, cm⁻¹): ν = 3434 (b), 2995 (m), 2942 (m), 2894 (m), 1703 (w), 1643 (s), 1462 (w), 1379 (m), 1273 (m), 1228 (s), 1200 (m), 1163 (m), 1118 (s), 1095 (s), 1061 (m), 1031 (m), 1005 (m), 944 (m), 873 (s), 816 (w), 755 (m). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 6.28 (dd, J = 5.0, 2.0 Hz, 1H), 4.72 (dd, J = 6.0, 2.0 Hz, 1H), 4.35-4.32 (m, 1H), 3.95-3.92 (m, 1H), 3.83-3.70 (m, 3H), 1.52 (s, 3H), 1.42 (s, 3H).

**32**

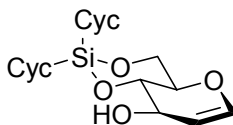
Compound (**32**) [BS-I-5]. An oven-dried 25 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **31** (360 mg, 1.94 mmol, 1.0 equiv) and CH₂Cl₂ (11.0 mL). The solution was cooled to 0 °C, and trichloroacetonitrile (0.58 mL, 5.81 mmol, 3.0 equiv) and DBU (58.0 μL, 0.39 mmol, 0.2 equiv) were sequentially added to the solution. The resulting mixture was stirred at 0 °C for 1 h and concentrated. The residue was purified by silica gel flash chromatography (5/1, hexane/ethyl acetate with 1% triethylamine) to give **32** (500 mg, 78%) as a white solid. $R_f = 0.68$ 5/1 H/EA. MP = 72. ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 8.35 (bs, 1H), 6.39 (d, J = 6 Hz, 1H), 5.54 (d, J = 7.5 Hz, 1H), 4.89 (dd, J = 6.0, 2.0 Hz, 1H), 4.2-4.17 (m, 1H), 3.98 (q, J = 4.0, 1H), 3.85 (t, 5.5 Hz, 2H), 1.5 (s, 3H), 1.40 (s, 3H). ¹³C-NMR (CDCl₃, 125 MHz, ppm): δ = 158, 146, 99.4, 83.0, 73.9, 70.0, 49.8, 61.7, 28.9, 19.0. IR (film, cm⁻¹): ν = 3337 (m), 2996 (w), 2952 (w), 2891 (w), 2871 (w), 1664 (s), 1641 (s), 1478 (w), 1455 (w), 1387 (w), 1374 (w), 1363 (w), 1334 (m), 1282 (m), 1266 (m), 1235 (m), 1199 (m), 1165 (m), 1110 (m), 1093 (s), 1063 (vs), 1015 (m), 992 (s), 948 (m), 871 (m), 840 (m), 820 (m), 797 (s), 759 (m), 644 (m).

**33**

Compound (**33**) [BS-I-18]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **32** (66 mg, 0.2 mmol, 1.0 equiv), 4-methoxyphenol, and CH_2Cl_2 (1.0 mL). The reaction was covered in aluminum foil. Once the solids dissolved, $\text{Pd}(\text{CH}_3\text{CN})_2\text{Cl}_2$ (1.3 mg, 0.005 mmol, 2.5% mol) was added. The resulting solution was stirred at room temperature for 3 h. The resulting mixture was purified by silica gel flash chromatography (8/1, hexane/ethyl acetate) to give **33** (45.0 mg, 77%). $R_f = 0.40$ (5/1; H/EA). MP: 107.1° C – 108.5° C. $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): $\delta = 6.97$ (d, $J = 8.5$ Hz, 2H), 6.81 (d, $J = 9.0$ Hz, 2H), 6.10 (d, $J = 10.0$ Hz, 1H), (dt, $J = 10.0, 2.5$ Hz, 1H), 5.51 (s, 1H), 4.22 (d, 7.5 Hz, 1H), 3.88 – 3.79 (m, 3H), 3.75 (s, 3H), 1.51 (s, 3H), 1.42 (s, 3H). $^{13}\text{C-NMR}$ (CDCl_3 , 75 MHz, ppm): $\delta = 155.1, 151.2, 132.5, 126.0, 118.5, 114.6, 100.0, 94.4, 67.5, 65.8, 63.0, 55.7, 29.2, 19.0$. IR (film, cm^{-1}): $\nu = 3054$ (w), 2993 (m), 2941 (m), 2918 (m), 2868 (m), 2837 (m), 1508 (s), 1375 (m), 1219 (s), 1093 (m), 1031 (m), 993 (s), 859 (m), 822 (s). HRMS: calc. for $\text{C}_{16}\text{H}_{21}\text{O}_5$ (M^+) 293.1384; found: 293.1383

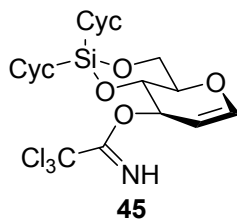
**35**

Compound (**35**) [BS-I-32]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). The resulting solution was stirred at room temperature for 4 h, 1-naphthol (58 mg, 0.4 mmol, 2.0 equiv), glucal imidate **32** (66 mg, 0.2 mmol, 1 equiv), and CH₂Cl₂ (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 6 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (15/1, hexane/ethyl acetate) to give **35** (52.0 mg, α : β = 20:1, 84%) as a white solid. R_f = 0.52 8/1 H/EA, MP = 134.7-134.9°C

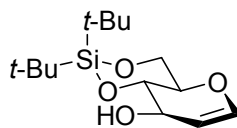
**44**

Compound (**44**) [BS-I-84]. An oven-dried 50 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with D-glucal (1.0 g, 6.84 mmol, 1.0 equiv),

imidazole (1.16 g, 17.1 mmol, 2.5 equiv), and dry DMF (30 mL). Once the D-glucal was fully dissolved, the reaction mixture was cooled to 0 °C and dicyclohexyldichlorosilane was added dropwise. The resulting reaction mixture was warmed to room temperature and allowed to stir for 20 h. The resulting reaction mixture was poured into H₂O (150 mL) and extracted with ether (100 mL). The organic layer was extracted and the aqueous layer was back extracted twice with ether (100 mL). All the organic layers were combined and dried over MgSO₄, filtered, and concentrated in vacuo. The resulting crude product was purified by silica gel flash chromatography (2/1. hexane/ethyl acetate) to yield **32** (0.54 g, 53 %). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 6.24 (dd, J = 6.0, 1.5 Hz, 1H), 4.73 (dd, J = 6.0, 1.8, 1H), 4.30-4.26 (m, 1H), 4.15-4.10 (m, 1H), 3.9-3.73 (m, 3H), 2.25 (d, J = 3.6 Hz, 1 H), 1.78-1.68 (m, 12H), 1.32-1.20 (m, 12H). ¹³C-NMR (CDCl₃, 75 MHz, ppm): δ = 143.7, 103.0, 72.7, 70.2, 65.4, 27.7, 27.6, 26.9, 26.8, 26.7, 26.2, 25.2, 23.5. IR (film, cm⁻¹): ν = 3441 (b), 2921 (vs), 2847 (s), 1646 (m), 1446 (m), 1231 (m), 1159 (m), 1120 (s), 1097 (s), 995 (m), 912 (m), 871 (m), 779 (m), 746 (m).



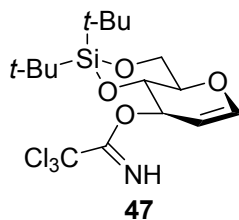
Compound (**45**). An oven-dried 50 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **44** (1.1 g, 3.22 mmol, 1.0 equiv) and CH₂Cl₂ (20 mL). The solution was cooled to 0 °C, and trichloroacetonitrile (0.65 mL, 6.44 mmol, 2.0 equiv) and DBU (96.0 μL, 0.65 mmol, 0.2 equiv) were sequentially added to the solution. The resulting mixture was stirred at 0 °C for 2 h and concentrated. The residue was purified by silica gel flash chromatography (15/1, hexane/ethyl acetate with 1% triethylamine) to give **45** (1.26 g, 81%). R_f = 0.49 15/1 H/EA. ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 8.3 (bs, 1H), 6.35 (dd, J= 6.3, 1.2 Hz, 1H), 5.48 (d, J = 7.2 Hz, 1H), 4.90-4.88 (m, 1H), 4.27 (t, J = 3.6 Hz, 1H), 4.18-4.15 (m, 1H), 3.98-3.86 (m, 2H), 1.74-1.67 (m, 12H), 1.41-1.19 (m, 12H). ¹³C-NMR (CDCl₃, 75 MHz, ppm): δ = 162.6, 145.5, 99.0, 73.2, 73.1, 65.6, 27.7, 27.6, 27.5, 26.9, 26.8, 26.8, 26.7, 26.1, 25.0, 23.4.

**46**

Compound (**46**) [BS-II-60]. An oven-dried 50 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with D-glucal (826 mg, 5.66 mmol, 1.0 equiv), and dry DMF (21 mL). Once the D-glucal was fully dissolved, the reaction mixture was cooled to -40 °C and (*t*-Bu)₂Si(OTf)₂ (2.74 g, 6.23 mmol, 1.1 equiv) was added dropwise

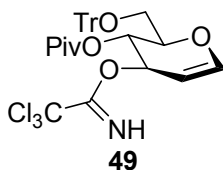
followed by pyridine (0.54 g, 6.79 mmol, 1.2 equiv). The resulting reaction mixture was warmed to room temperature and allowed to stir for 1 h. The resulting reaction mixture was poured into ether (50 mL) and NaHCO₃ (20 mL) was added. The organic layer was extracted and the aqueous layer was back extracted twice with ether (20 mL). All the

organic layers were combined and dried over MgSO₄, filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash chromatography (9/1. hexane/ethyl acetate) to yield **46** (569 mg, 69 %) as a white solid. ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 8.33 (bs, 1H), 6.35 (dd, J = 6.0, 1.5 Hz, 1H), 5.51 (dd, J = 7.5, 6.0 Hz, 1H), 4.91-4.89 (m, 1H), 4.34-4.31 (m, 1H), 4.22-4.19 (m, 1H), 4.20-3.95 (m, 2H), 1.03 (s, 9H), 0.97 (s, 9H).

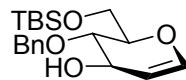


Compound (**47**) [BS-I-60]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **46** (450 mg, 1.57 mmol, 1.0 equiv) and CH₂Cl₂ (9 mL). The solution was cooled to 0 °C, and trichloroacetonitrile (0.79 mL, 7.87 mmol, 5.0 equiv) and DBU (47.0 μL, 0.32 mmol, 0.2 equiv) were sequentially added to

the solution. The resulting mixture was stirred at 0 °C for 1 h and concentrated. The residue was purified by silica gel flash chromatography (9/1, hexane/ethyl acetate with 1% triethylamine) to give **47** (579 mg, 86%). $R_f = 0.25$ 9/1 H/EA.

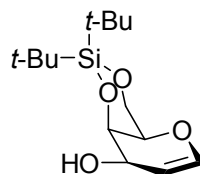


Compound (**49**) [BS-II-49]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **48** (325 mg, 0.69 mmol, 1.0 equiv) and CH_2Cl_2 (4 mL). The solution was cooled to 0 °C, and trichloroacetonitrile (0.21 mL, 2.07 mmol, 3.0 equiv) and DBU (21.0 μL , 0.14 mmol, 0.2 equiv) were sequentially added to the solution. The resulting mixture was stirred at 0 °C for 1 h and concentrated. The residue was purified by silica gel flash chromatography (5/1, hexane/ethyl acetate with 1% triethylamine) to give **49** (392 mg, 92%). $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): $\delta = 8.29$ (bs, 1H), 7.43 (d, $J = 8.0$ Hz, 6H), 7.28-7.26 (m, 6H), 7.21-7.18 (m, 3H), 6.59 (d, $J = 6.5$ Hz, 1H), 5.21 (t, $J = 4.0$ Hz, 1H), 5.16 (t, $J = 5.0$ Hz, 1H), 5.02-5.00 (m, 1H), 4.34-4.32 (m, 1H), 3.68-3.64 (m, 1H), 3.12 (dd, $J = 10.5, 2.0$ Hz, 1H), 1.05 (s, 9H).

**50**

Compound (**50**) [BS-I-59]. IR (film, cm^{-1}): $\nu = 3434$ (b), 3062 (w), 3027 (w), 2953 (s), 2928 (s), 2882 (m), 2856 (s), 1646 (m), 1462 (m), 1404 (w), 1386 (w), 1358 (w), 1322 (w), 1252 (s), 1236 (s), 1167 (w), 1105 (vs), 1050 (s), 969 (m), 955 (m), 876 (m), 837 (vs), 777 (s), 749 (s), 698 (s). $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): $\delta = 7.36$ -7.33

(m, 4H), 7.30-7.26 (m, 1H), 6.34 (dd, $J = 6.0$ 1.0 Hz, 1H), 4.77 (s, 2H), 4.71-4.69 (m, 1H), 4.28-4.27 (m, 1H), 3.94 (d, $J = 2.0$ Hz, 2H), 3.84 (dt, $J = 8.5$, 3.0 Hz, 1 H), 3.68-3.65 (m, 1H), 2.21 (d, $J = 6.5$ Hz, 1H), 0.90 (s, 9H), 0.08 (s, 6H). $^{13}\text{C-NMR}$ (CDCl_3 , 125 MHz, ppm): $\delta = 144.5$, 138.5, 128.6, 127.9, 102.2, 77.0, 76.7, 73.7, 68.1, 62.4, 25.9, 18.4, -5.1, -5.4.

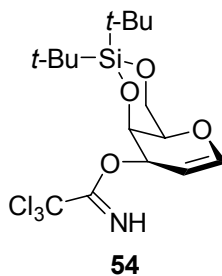
**53**

Compound (**53**) [BS-II-11]. An oven-dried 25 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with D-galactal (486 mg, 3.33 mmol, 1.0

equiv), and dry DMF (15 mL). Once the D-galactal was fully dissolved, the reaction mixture was cooled to $-40\text{ }^{\circ}\text{C}$ and $(t\text{-Bu})_2\text{Si}(\text{OTf})_2$ (1.33 mL, 3.7 mmol, 1.1 equiv) was added dropwise followed by pyridine (0.32 mL, 4.0 mmol, 1.2 equiv). The resulting reaction mixture was warmed to room temperature and allowed to stir for 1 h. The resulting reaction mixture was poured into ether (100 mL) and NaHCO_3 (150 mL) was added. The organic layer was extracted and the aqueous layer was back extracted twice with ether (100 mL). All the organic layers were combined and dried over MgSO_4 ,

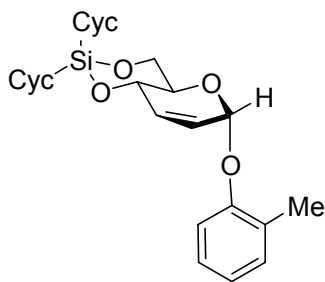
filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash chromatography (6/1 hexane/ethyl acetate) to yield **53** (342 mg, 36 %) as a white solid.

$^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): $\delta = 6.23$ (dd, $J = 6.5, 2.0$ Hz, 1H), 4.77 (s, 1H), 4.69 (dt, $J = 6.5, 1.5$ Hz, 1H), 4.42 (d, $J = 4.0$ Hz, 1H), 4.26-4.19 (m, 2H), 3.85 (s, 1H), 1.05 (s, 9H), 1.00 (s, 9H). IR (film, cm^{-1}): $\nu = 3441$ (b), 2960 (m), 2942 (m), 2897 (m), 2859 (s), 2360 (s), 1650 (m), 1474 (m), 1237 (m), 1168 (s), 1076 (vs), 902 (vs), 826 (m), 801 (m), 746 (s).



Compound (**54**). An oven-dried 25 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with **53** (334 mg, 1.17 mmol, 1.0 equiv) and CH₂Cl₂ (7 mL). The solution was cooled to 0 °C, and trichloroacetonitrile (0.59 mL, 5.84 mmol, 5.0 equiv) and DBU (35.0 μL, 0.23 mmol, 0.2 equiv) were sequentially added to the solution. The resulting mixture was stirred at 0 °C for 2 h and concentrated. The residue was

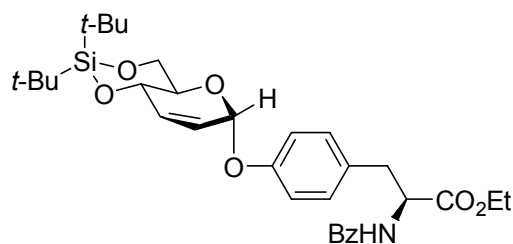
purified by silica gel flash chromatography (9/1, hexane/ethyl acetate with 1% triethylamine) to give **54** (381 mg, 76%).

**57**

Compound (**57**) [BS-I-75]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). The resulting solution was stirred at room temperature for 4 h, *ortho*-methylphenol (43.2 mg, 0.4 mmol, 2.0 equiv), glucal imidate **45** (96.2 mg, 0.2 mmol, 1 equiv), and CH₂Cl₂ (0.5 mL)

were sequentially added to the solution. The resulting mixture was stirred for 10 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (40/1, hexane/ethyl acetate) to give **57** (68.2 mg, $\alpha:\beta = 7:1$, 80%). $R_f = 0.32$ 40/1 H/EA. $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): $\delta = 7.13$ (t, $J = 8.0$ Hz, 2H), 7.07 (d, $J = 7.5$ Hz, 1H), 6.92 (t, $J = 7.0$ Hz, 1H), 6.12 (d, $J = 10.5$ Hz, 1H), 5.83 (dt, $J = 10.0, 2.5$ Hz, 1H), 5.55 (s, 1H), 4.35 (d, $J = 5.0$ Hz, 1H), 4.09 – 4.08 (m, 1H), 3.86 – 3.82 (m, 2H), 2.23 (s, 3H), 1.75 – 1.68 (m, 12H), 1.28 – 1.19 (m, 12H). $^{13}\text{C-NMR}$ (CDCl_3 , 125 MHz, ppm): $\delta = 155.7$,

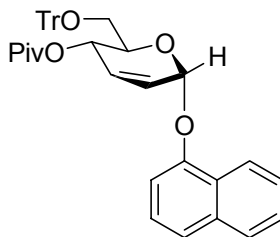
134.6, 130.8, 128.0, 126.9, 124.8, 122.2, 115.4, 93.7, 69.7, 68.5, 66.7, 31.6, 27.8, 27.7, 27.6, 26.9, 26.8, 26.8, 26.7, 26.2, 25.3, 23.8, 22.6, 16.3. IR (film, cm^{-1}): $\nu = 2921$ (s), 2847 (m), 1493 (m), 1449 (m), 1400 (w), 1234 (m), 1195 (w), 1138 (m), 1127 (m), 1114(m), 1103 (m), 1087 (s), 1021 (m), 994 (m), 891 (m), 862 (s), 749 (m), 717 (m), 668 (vs). HRMS: calc. for $\text{C}_{25}\text{H}_{36}\text{O}_4\text{SiNa}$ $[\text{M}+\text{Na}]^+$ 451.2275; found: 451.2250

**58**

Compound (**58**) [BS-II-67]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). The resulting solution was stirred at room temperature for 4 h, *N*-benzoyl-L-tyrosine ethyl ester (94 mg, 0.3 mmol, 1.5 equiv), glucal imidate **47** (86.2 mg, 0.2 mmol, 1 equiv), and CH₂Cl₂ (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 6 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (30/1, hexane/ethyl acetate) to give **58** (81.0 mg, α only, 73%). ¹H-NMR (CDCl₃, 500 MHz,

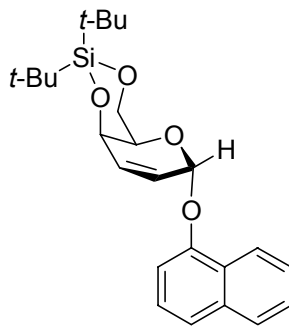
ppm): δ = 7.71 (d, *J* = 7.5, 2H), 7.48 (t, *J* = 7.5, 1H), 7.40 (t, *J* = 7.5, 2H), 7.04 (d, *J* = 8.5 Hz, 2H), 6.96 (d, *J* = 8.5 Hz, 2H), 6.65 (d, *J* = 7.5 Hz, 1H), 6.14 (d, *J* = 10.5 Hz, 1H), 5.76 (m, 1H), 5.54 (s, 1H), 5.0 (q, *J* = 6.0 Hz, 1H), 4.40 (d, *J* = 6.5 Hz, 1H), 4.20 (q, *J* = 7.0 Hz, 2H), 4.09 (q, *J* = 5.0 Hz, 1H), 3.87 (q, *J* = 5.5 Hz, 2H), 3.19 (qd, *J* = 15.5, 5.5 Hz, 2H), 1.27 (t, *J* = 7.0 Hz, 3H), 1.04 (s, 9H), 0.96 (s, 9H). ¹³C-NMR (CDCl₃, 125 MHz, ppm): δ = 171.7, 166.8, 156.6, 135.3, 133.9, 131.8, 130.5, 129.5, 128.6, 127.0, 124.1, 116.9, 93.3, 70.1, 68.1, 67.0, 61.7, 53.6, 37.1, 27.4, 27.0, 22.7, 20.0, 14.1. IR (film, cm⁻¹): ν = 3342 (m), 3298 (m), 3183 (w), 3060 (w), 2964 (m), 2934 (s), 2896 (m), 2860 (s), 1732 (s), 1649 (s), 1611 (m), 1580 (m), 1530 (m), 1510 (s), 1486 (m), 1474 (m), 1445 (m), 1397 (m), 1375 (m), 1365 (m), 1350 (m), 1318 (m), 1306 (m), 1272 (m), 1226 (s), 1186 (m), 1132 (vs), 1107 (s), 1090 (s), 1073 (m), 1025 (s), 993 (s), 938 (w), 911 (m),

884 (w), 859 (s), 826 (s), 761 (m), 734 (m), 714 (m), 693 (m), 653 (m). HRMS: calc. for $C_{32}H_{43}NO_7SiNa$ $[M+Na]^+$ 604.2701; found: 604.2709.

**59**

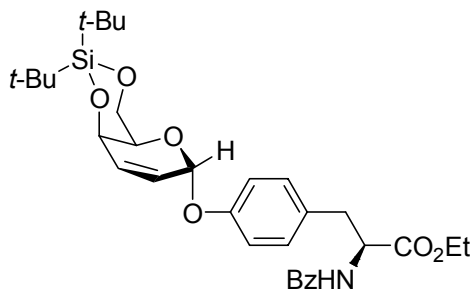
Compound (**59**) [BS-II-45]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $Pd(PhCN)_2Cl_2$ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). The resulting solution was stirred at room temperature for 4 h, 1-naphthol (58 mg, 0.4 mmol, 2.0 equiv), glucal imidate **49** (123 mg, 0.2 mmol, 1 equiv), and CH_2Cl_2 (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 6 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (30/1, hexane/ethyl acetate) to give **59** (91.0 mg, $\alpha:\beta = 10:1$, 76%). $R_f = 0.48$ (9/1; H/EA). 1H -NMR ($CDCl_3$, 500 MHz, ppm): $\delta = 8.29$ (dd, $J = 8.3, 1.5$ Hz, 1H), 7.84 (dd, $J = 8.3, 1.5$ Hz, 1H), 7.53 (dd, $J = 8.0, 4.0$ Hz, 2H), 7.49 (t, $J = 7.5$ Hz, 1H), 7.41 (d, $J = 8$ Hz, 2H), 7.37 (d, $J = 7$ Hz, 6H), 7.22 – 7.17

(m, 9H), 6.15 (dt, $J = 10, 2.5$ Hz, 1H), 6.04 (d, $J = 10$ Hz, 1H), 6.00 (s, 1H), 5.41 (d, $J = 9$ Hz, 1H), 4.33-4.30 (m, 1H), 3.16 (dd, $J = 10.0, 6.0$ Hz, 1H), 3.11 (dd, $J = 10, 1.5$ Hz, 1H) 0.99 (s, 9H). ^{13}C -NMR (CDCl_3 , 125 MHz, ppm): $\delta = 177.5, 153.1, 143.8, 134.6, 131.2, 128.8, 128.7, 128.5, 127.8, 127.7, 127.6, 127.0, 126.9, 126.8, 126.3, 126.1, 125.8, 125.4, 122.1, 121.9, 121.8, 109.6, 93.2, 86.3, 69.8, 65.1, 62.6, 38.6, 27.0, 26.9$. IR (film, cm^{-1}): $\nu = 3057$ (m), 2973 (m), 2931 (m), 2874 (m), 1732 (s), 1596 (m), 1578 (m), 1507 (m), 1490 (m), 1479 (m), 1463 (m), 1448 (m) 1396 (m), 1280 (m), 1263 (m), 1237 (m), 1149 (s), 1085 (m), 1051 (m), 1016 (m), 976 (s), 910 (m), 792 (m), 772 (m), 733 (m), 706 (m), 667 (m). HRMS: calc. for $\text{C}_{40}\text{H}_{38}\text{O}_5\text{Na}$ $[\text{M}+\text{Na}]^+$ 621.2611; found: 621.2609

**60**

Compound (**60**) [BS-II-6]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). The resulting

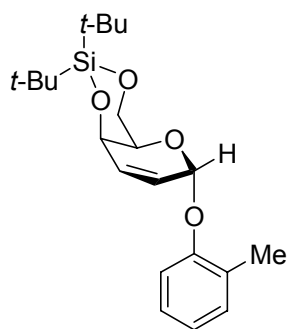
solution was stirred at room temperature for 4 h, 1-naphthol (57.7 mg, 0.4 mmol, 2.0 equiv), galactal imidate **54** (85.8 mg, 0.2 mmol, 1 equiv), and CH₂Cl₂ (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 2 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (50/1, hexane/ethyl acetate) to give **60** (63.2 mg, α only, 76%). MP = 141°C. ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 8.16 (d, J = 8 Hz, 1H), 7.79 (d, J = 7.5 Hz, 1H), 7.50 – 7.38 (m, 4H), 7.32 (d, J = 7.5 Hz, 1H), 6.31 (dd, J = 9.5, 5.5 Hz, 1H), 6.14 (dd, J = 10.0, 3.0 Hz, 1H), 5.92 (d, J = 3 Hz, 1H), 4.42 (dd, J = 5.0, 2.5 Hz, 1H), 4.33 (d, J = 12.5 Hz, 1H), 4.14 (d, J = 12.5 Hz, 1H), 4.08 (d, J = 1.5 Hz, 1H), 1.05 (s, 9H), 1.03 (s, 9H). ¹³C-NMR (CDCl₃, 125 MHz, ppm): δ = 153.1, 134.5, 130.3, 127.6, 126.2, 126.1, 126.0, 125.3, 121.9, 121.6, 109.2, 93.7, 68.1, 66.3, 64.7, 27.5, 27.1, 23.1, 20.6. IR (film, cm⁻¹): ν = 3052 (w), 2963 (m), 2932 (s), 2886 (m), 2858 (s), 1598 (w), 1578 (m), 1507 (w), 1464 (m), 1398 (s), 1362 (w), 1264 (m), 1238 (m), 1195 (m), 1140 (s), 1124 (m), 1075 (s), 1049 (s), 1016 (m), 966 (s), 906 (s), 888 (s), 826 (m), 795 (s), 771 (s), 743 (s), 706 (m). HRMS: calc. for C₂₄H₃₂O₄SiNa [M+Na]⁺ 435.1962; found: 435.1951.

**61**

Compound (**61**) [BS-II-1]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). The resulting solution was stirred at room temperature for 4 h, *N*-benzoyl-L-tyrosine ethyl ester (125.3 mg, 0.4 mmol, 2.0 equiv), galactal imidate **54** (85.8 mg, 0.2 mmol, 1 equiv), and CH₂Cl₂ (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 10 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (4/1, hexane/ethyl acetate) to give **61** (113.1 mg, α only, 97%). MP = 47°C. ¹H-NMR (CDCl₃,

300 MHz, ppm): δ = 7.72 (d, J = 11.5 Hz, 2H), 7.50 – 7.39 (m, 3H), 7.056 – 6.991 (m, 4H), 6.59 (d, J = 12.0 Hz, 1H), 6.22 (q, J = 8.5 Hz, 1H), 5.98 (dd, J = 16.5, 5.5 Hz, 1H), 5.69 (d, J = 4.5 Hz, 1H), 5.02 (q, J = 12.0 Hz, 1H), 4.37 – 4.31 (m, 2H), 4.21 (q, J = 12.0 Hz, 2H), 4.11 (d, J = 21.0 Hz, 1H), 3.97 (s, 1H), 3.20 (hept., J = 8.5 Hz, 2H), 1.28 (t, J = 12.0 Hz, 3 H), 1.03 (s, 9H), 0.99 (s, 9H). ¹³C-NMR (CDCl₃, 75 MHz, ppm): δ = 171.7,

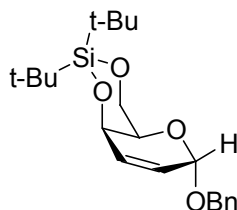
156.6, 131.8, 130.5, 130.3, 129.4, 128.7, 127.1, 126.0, 116.9, 93.4, 67.9, 66.2, 64.7, 61.7, 53.7, 37.2, 27.5, 27.1, 23.1, 20.6, 14.2. IR (film, cm^{-1}): $\nu = 3344$ (m), 3282 (m), 3183 (m), 2963 (m), 2933 (s), 2893 (m), 2858 (s), 1726 (s), 1650 (s), 1602 (m), 1509 (s), 1474 (m), 1374 (m), 1227 (s), 1142 (s), 1076 (s), 980 (s), 905 (m), 887 (m), 826 (s), 792 (m), 714 (m). HRMS: calc. for $\text{C}_{32}\text{H}_{43}\text{NO}_7\text{Si}$ (M^+) 582.2882; found: 582.2854

**62**

Compound (**62**) [BS-I-92]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ (1.9 mg, 0.005 mmol,

2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). The resulting solution was stirred at room temperature for 4 h, *ortho*-methylphenol (43.3 mg, 0.4 mmol, 2.0 equiv), galactal imidate **54** (85.8 mg, 0.2 mmol, 1 equiv), and CH_2Cl_2 (0.5 mL) were sequentially added to the solution. The resulting mixture was stirred for 10 h,

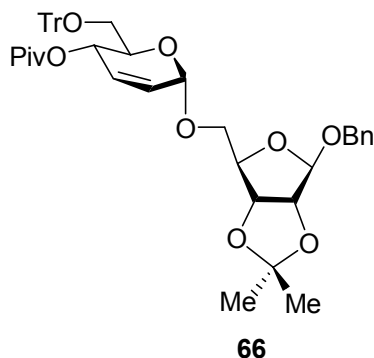
diluted with benzene (1 mL), and purified by silica gel flash chromatography (30/1, hexane/ethyl acetate) to give **62** (61 mg, α only, 81%). MP = 58°C. $^1\text{H-NMR}$ (CDCl_3 , 300 MHz, ppm): δ = 7.22 (s, 1H), 7.17-7.11 (m, 2H), 6.91 (t, J = 12.0 Hz, 1H), 6.23 (dd, 16.5, 9.0 Hz, 1H), 6.01 (dd, 16.5, 5.0 Hz, 1H), 5.68 (d, 4.5 Hz, 1H), 4.38- 4.32 (m, 2H), 4.15 (d, J = 21.0 Hz, 1H), 4.02 (d, J = 3.0 Hz, 1H), 2.18 (s, 3H), 1.04 (s, 9H), 1.0 (s, 9H). $^{13}\text{C-NMR}$ (CDCl_3 , 75 MHz, ppm): δ = 130.7, 130.0, 127.0, 126.4, 122.0, 115.5, 93.9, 67.9, 66.3, 64.8, 27.5, 27.1, 23.2, 20.7, 16.3. IR (film, cm^{-1}): ν = 3050 (w), 2933 (s), 2890 (m), 2858 (s), 1591 (m), 1493 (s), 1473 (m), 1400 (m), 1363 (m), 1339 (w), 1301 (w), 1236 (s), 1188 (m), 1144 (vs), 1123 (m), 1096 (m), 1077 (s), 1049 (w), 986 (vs), 905 (m), 887 (m), 858 (w), 826 (m), 796 (m), 782 (w), 750 (s), 711 (m). HRMS: calc. for $\text{C}_{21}\text{H}_{32}\text{O}_4\text{SiNa}$ $[\text{M}+\text{Na}]^+$ 399.1962; found: 399.2002.

**64**

Compound (**64**) [BS-II-15]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, benzyl alcohol (32 μL, 0.3 mmol, 1.5 equiv), CH₂Cl₂ (0.5 mL), toluene (0.5 mL), and ZnEt₂ (150 μL, 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and galactal imidate **54** (85.8 mg, 0.2 mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (20/1, hexane/ethyl acetate) to give **62** (58.3 mg, α only, 77%).

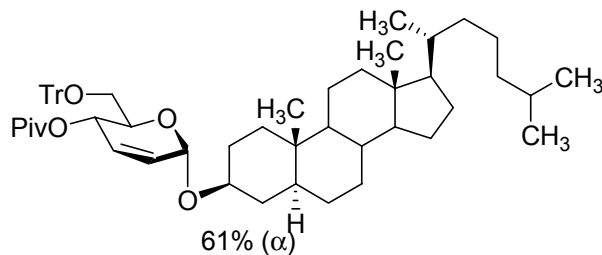
¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 7.33 – 7.32 (m, 4H), 7.29 – 7.25 (m, 1H), 6.09 (dd, J = 10.0, 5.0 Hz, 1H), 5.88 (dd, J = 10.0, 3.5 Hz, 1H), 5.13 (d, J = 3.0 Hz, 1H), 4.68 (q, 12.0 Hz, 2H), 4.33 (dd, 12.5, 2.0 Hz, 1H), 4.27 (dd, 5.0, 2.5 Hz, 1H), 4.11 (dd, J = 12.5, 1.5 Hz, 1H), 3.89 – 3.88 (m, 1H), 1.03 (s, 9H), 0.97 (s, 9H). ¹³C-NMR (CDCl₃, 125

MHz, ppm): δ = 138.1, 129.5, 128.4, 127.9, 127.6, 126.9, 94.0, 69.8, 67.2, 66.3, 64.9, 30.3, 27.5, 27.1, 23.1, 20.5. IR (film, cm^{-1}): ν = 2935 (s), 2886 (m), 2858 (s), 1470 (m), 1363 (m), 1195 (m), 1142 (vs), 1121 (m), 1079 (m), 1040 (s), 1025 (s), 987 (m), 825 (m), 795 (s), 745 (m), 696 (m). HRMS: calc. for $\text{C}_{21}\text{H}_{32}\text{O}_4\text{SiNa}$ $[\text{M}+\text{Na}]^+$ 399.1962; found: 399.1946.



Compound (**66**) [BS-II-59]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, dry furanose alcohol (azeotroped with toluene three times) (120 mg, 0.3 mmol, 1.5 equiv), CH_2Cl_2 (0.5 mL), toluene (0.5 mL), and ZnEt_2 (150 μL , 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and glucal imidate **49** (111 mg, 0.2

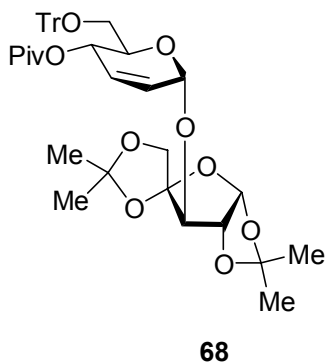
mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (9/1, hexane/ethyl acetate) to give **66** (117.9 mg, α only, 88%). $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, ppm): δ = 7.45 (d, J = 8.0 Hz, 6H), 7.28 – 7.25 (m, 9H), 7.21 – 7.17 (m, 5H), 5.79 (s, 2H), 5.21 (d, J = 9.5 Hz, 1H), 5.16 (s, 1H), 5.09 (s, 1H), 4.75 (q, 46.0, 6.0 Hz, 2H), 4.61 (d, 12.0 Hz, 1H), 4.51 (q, J = 4.5 Hz, 1H), 4.40 (d, J = 12.0 Hz, 1H), 4.15 – 4.10 (m, 2H), 3.63 (t, J = 10.0 Hz, 1H), 3.12 – 3.10 (m, 2H), 1.43 (s, 3H), 1.30 (s, 3H), 0.95 (s, 9H). $^{13}\text{C-NMR}$ (CDCl_3 , 125 MHz, ppm): δ = 177.5, 143.9, 137.1, 129.9, 128.7, 128.4, 128.0, 127.8, 127.4, 126.9, 112.4, 107.3, 96.5, 94.7, 86.4, 85.5, 85.4, 85.4, 85.3, 82.5, 82.2, 74.9, 69.1, 69.0, 68.8, 68.4, 65.3, 64.7, 62.9, 38.6, 26.9, 26.8, 26.4, 25.0. IR (film, cm^{-1}): ν = 3061 (w), 3031 (w), 2976 (m), 2935 (m), 2901 (w), 2874 (w), 1732 (s), 1490 (w), 1450 (m), 1372 (w), 1278 (m), 1210 (m), 1152 (s), 1077 (s), 1040 (s), 1016 (s), 913 (s), 870 (m), 744 (s), 699 (s), 668 (m), 633 (m). HRMS: calc. for $\text{C}_{45}\text{H}_{50}\text{O}_9\text{SiNa}$ $[\text{M}+\text{Na}]^+$ 757.3347; found: 757.3359.

**67**

Compound (**67**) [BS-II-38]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, dry 3 β -cholestanol (azeotroped with toluene three times) (116.6 mg, 0.3 mmol, 1.5 equiv), CH₂Cl₂ (0.5 mL), toluene (0.5 mL), and ZnEt₂ (150 μ L, 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and glucal imidate **49** (123.4 mg, 0.2 mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (45/1, hexane/ethyl acetate) to give **67** (99.1 mg, α only, 61%). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 7.46 (d, J = 7.0 Hz, 6H), 7.27 – 7.24 (m, 6H), 7.20 (t, J = 7.0 Hz, 3H), 5.79-5.78 (m, 1H), 5.27 (d, J = 10.0 Hz, 1H), 5.14 (d, J = 10.0 Hz, 1H), 4.20 – 4.17 (m, 1H), 4.19 (hex, J = 5.0 Hz, 1H), 3.22 – 3.08 (m, 2H), 1.95 (d, J = 12.5 Hz, 1H), 1.80 – 0.96 (m, 24H), 0.94 (s,

9H), 0.88 (d, $J = 7.0$ Hz, 3H), 0.84 (dd, $J = 7.0, 2.5$ Hz, 6H), 0.63 (s, 3H), 0.51 (s, 3H).
 ^{13}C -NMR (CDCl_3 , 125 MHz, ppm): $\delta = 144.0, 129.5, 128.7, 128.4, 127.7, 126.9, 91.9,$
68.5, 65.5, 63.4, 56.5, 56.3, 54.3, 45.1, 40.0, 39.5, 36.9, 36.3, 36.2, 35.8, 35.5, 32.1, 28.7,
28.3, 28.0, 27.7, 26.9, 26.8, 24.2, 23.8, 22.8, 22.5, 21.2, 18.7, 12.3, 12.1. IR (film, cm^{-1}):
 $\nu = 3059$ (w), 2932 (vs), 2868 (s), 1733 (s), 1499 (m), 1448 (m), 1382 (m), 1280 (m),

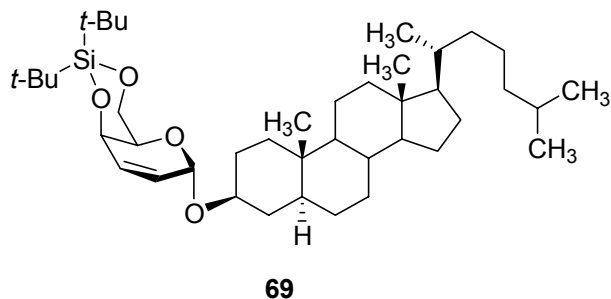
1150 (s), 1035 (m), 1075 (m), 1035 (vs), 909 (m), 764 (m), 734 (s), 705 (s). HRMS: calc.
for $\text{C}_{57}\text{H}_{78}\text{O}_5\text{Na}$ $[\text{M}+\text{Na}]^+$ 865.5741; found: 865.5746.



Compound (**68**) [BS-II-23]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). A second

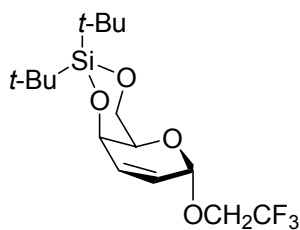
oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, dry diacetone D-glucose (azeotroped with toluene three times) (78.1 mg, 0.3 mmol, 1.5 equiv), CH₂Cl₂ (0.5 mL), toluene (0.5 mL), and ZnEt₂ (150 μL, 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and glucal imidate **49** (123.4 mg, 0.2 mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with

benzene (1 mL), and purified by silica gel flash chromatography (4/1, hexane/ethyl acetate) to give **68** (94.9 mg, α only, 66%). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 7.45 (d, J = 7.5 Hz, 6H), 7.27 (t, J = 7.5 Hz, 6H), 7.20 (t, J = 7.5 Hz, 3H), 5.92 (d, J = 3.5 Hz, 1H), 5.80 (s, 2H), 5.14 (d, J = 10 Hz, 1H), 4.85 (d, J = 3.0 Hz, 1H), 4.42 (d, J = 2.5 Hz, 1H), 4.23 – 4.20 (m, 1H), 4.15 – 4.10 (m, 3H), 4.00 – 3.97 (m, 1H), 3.15 (m, 2H), 1.48 (s, 3H), 1.43 (s, 3H), 1.34 (s, 3H), 1.02 (s, 3H), 0.95 (s, 9H). ¹³C-NMR (CDCl₃, 125 MHz, ppm): δ = 177.5, 143.7, 129.9, 128.8, 127.8, 127.0, 126.9, 105.4, 95.9, 84.3, 82.0, 81.4, 72.6, 69.2, 67.8, 65.3, 63.4, 27.7, 27.0, 26.8, 26.2, 25.4. IR (film, cm⁻¹): ν = 3060 (w), 3023 (w), 2984 (m), 2981 (m), 2963 (m), 2931 (m), 1734 (s), 1490 (w), 1449 (m), 1372 (m), 1280 (m), 1252 (w), 1217 (m), 1150 (s), 1073 (s), 1035 (s), 983 (s), 850 (m), 765 (m), 745 (m), 706 (s). HRMS: calc. for C₄₂H₅₀O₁₀Na [M+Na]⁺ 737.3296; found: 737.3283.



Compound (**69**) [BS-II-26]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, dry 3β-cholestanol (azeotroped with toluene three times) (116.6, 0.3 mmol, 1.5 equiv), CH₂Cl₂ (0.5 mL), toluene (0.5 mL), and ZnEt₂ (150 μL, 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and galactal imidate **54** (85.8 mg, 0.2 mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (30/1, hexane/ethyl acetate) to give **69** (92.0 mg, α only, 70%). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 6.06 (dd, J = 10.0, 5.5 Hz, 1H), 5.83 (dd, 10.0, 3.0 Hz, 1H), 5.15, (d, 4.0 Hz, 1H), 4.36 (dd, J = 12.3, 1.5 Hz, 1H), 4.25 (q, J = 3.0 Hz, 1H), 4.13 (dd, J = 12.3, 1.5 Hz, 1H), 3.91 (d,

2.0Hz, 1H), 3.64 (hept., $J = 5.0$ Hz, 1H), 1.93 (dt, $J = 13.0, 3.5$ Hz, 1H), 1.82 – 1.75 (m, 2H), 1.69 (dt, $J = 10.0, 3.0$ Hz, 1H), 1.62 (dq, $J = 9.5, 3.5$ Hz, 1H), 1.56 – 1.05 (m, 22H), 1.04 – 1.00 (m, 1H), 1.03 (s, 9H), 0.99 – 0.94 (m, 2H), 0.96 (s, 9H), 0.87 (d, $J = 6.5$ Hz, 3H), 0.84 (dd, $J = 6.5, 2.0$ Hz, 6H), 0.76 (s, 3H), 0.62 (s, 3H). ^{13}C -NMR (CDCl_3 , 125 MHz, ppm): $\delta = 129.2, 127.5, 93.0, 76.9, 66.9, 66.4, 65.1, 56.5, 56.3, 54.4, 45.0, 42.6, 40.0, 39.5, 37.0, 36.4, 36.2, 35.8, 35.5, 32.1, 28.8, 28.2, 28.0, 27.5, 27.1, 24.2, 23.8, 23.1, 22.8, 22.5, 21.2, 18.7, 12.2, 12.1$. IR (film, cm^{-1}): $\nu = 2932$ (vs), 2858 (s), 1172 (m), 1384 (m), 1143 (s), 1033 (s), 987 (m), 903 (m), 886 (m), 826 (m), 797 (m). HRMS: calc. for $\text{C}_{41}\text{H}_{72}\text{O}_4\text{SiNa}$ $[\text{M}+\text{Na}]^+$ 679.5092; found: 679.5094.



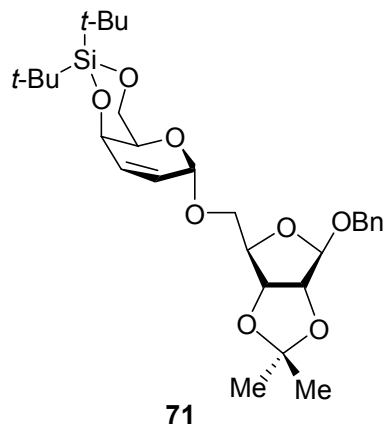
70

Compound (**70**) [BS-I-91]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with $\text{Pd}(\text{PhCN})_2\text{Cl}_2$ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH_2Cl_2 (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, 2,2,2-trifluoroethanol (29 μL , 0.4 mmol, 2.0 equiv), CH_2Cl_2 (0.5 mL), toluene (0.5 mL), and ZnEt_2 (150 μL , 0.15 mmol, 0.75 equiv). The resulting solutions

were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and galactal imidate **54** (85.8 mg, 0.2 mmol, 1.0 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 1 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (30/1, hexane/ethyl acetate) to give **70** (58.2 mg, α only, 79%).

$^1\text{H-NMR}$ (CDCl_3 , 300 MHz, ppm): δ = 6.15 (dd, J = 9.8, 5.4 Hz, 1H), 5.88 (dd, J = 10.0, 3.0 Hz, 1H), 5.11 (d, J = 3.0 Hz, 1H), 4.37 (dd, J = 12.6, 1.5 Hz, 1H), 4.30 (dd, J = 5.4, 2.7 Hz, 1H), 4.16 (dd, J = 12.6, 1.5 Hz, 1H), 4.08 – 3.92 (m, 2H), 3.86 (d, J = 2.1 Hz, 1H), 1.03 (s, 9H), 0.96 (s, 9H). $^{13}\text{C-NMR}$ (CDCl_3 , 75 MHz, ppm): δ = 130.4, 125.5, 95.1, 67.6, 66.1, 64.9, 64.6, 64.4, 27.5, 27.1, 23.2, 20.6. IR (film, cm^{-1}): ν = 2935 (s), 2891 (m),

2856 (s), 1475 (m), 1428 (w), 1400 (w), 1384 (w), 1363 (w), 1342 (w), 1284 (s), 1200 (m), 1162 (s), 1147 (vs), 1127 (s), 1063 (vs), 1001 (s), 981 (s), 936 (m), 899 (m), 882 (m), 848 (w), 827 (s), 794 (s), 772 (w), 752 (w), 718 (w), 681 (m). HRMS: calc. for $\text{C}_{16}\text{H}_{27}\text{O}_4\text{F}_3\text{Si}$ $[\text{M}+\text{Na}]^+$ 391.1523; found: 391.2843



Compound (**71**) [BS-II-64]. An oven-dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with Pd(PhCN)₂Cl₂ (1.9 mg, 0.005 mmol, 2.5% mol), DTTBP (2.1 mg, 0.005 mmol, 2.5% mol) and CH₂Cl₂ (0.5 mL). A second oven dried 10 mL Schlenk flask was equipped with a Teflon coated spin bar and charged with, in order, dry XXXXXXXXX (azeotroped with toluene three times) (32 μL, 0.3 mmol, 1.5 equiv), CH₂Cl₂ (0.5 mL), toluene (0.5 mL), and ZnEt₂ (150 μL, 0.15 mmol, 0.75 equiv). The resulting solutions were stirred at room temperature for 6 h. The catalyst solution was added to the aliphatic alcohol solution and galactal imidate **54** (84.1 mg, 0.3 mmol, 1.5 equiv), and 2,6-*di-tert*-butylphenol (20.6 mg, 0.1 mmol, 0.5 equiv) were sequentially added to the solution. The resulting mixture was stirred for 12 h, diluted with benzene (1 mL), and purified by silica gel flash chromatography (9/1, hexane/ethyl acetate) to give **71** (83.4 mg, α only, 76%). ¹H-NMR (CDCl₃, 500 MHz, ppm): δ = 7.34 –

7.26 (m, 5H), 6.06 (dd, J = 10.0, 5.5 Hz, 1H), 5.83 (dd, J = 10.0, 5.5 Hz, 1H), 5.13 (s, 1H), 5.03 (d, J = 3.0 Hz, 1H), 4.72 – 4.65 (m, 3H), 4.44 – 4.38 (m, 2H), 4.27 (dd, J = 12.5, 1.5 Hz, 1H), 4.24 (dd, J = 5.5, 2.5 Hz, 1H), 4.13 (dd, J = 12.5, 1.5 Hz, 1H), 3.83 – 3.80 (m, 2H), 3.57 (t, J = 10.0 Hz, 1H), 1.45 (s, 3H), 1.29 (s, 3H), 1.02 (s, 9H), 0.96 (s, 9H). ¹³C-NMR (CDCl₃, 125 MHz, ppm): δ = 137.1, 129.4, 128.5, 127.9, 127.8, 126.7, 112.4, 107.2, 95.4, 85.5, 85.4, 82.2, 69.4, 69.1, 67.2, 66.2, 64.8, 27.5, 27.1, 26.5, 25.0, 23.1, 20.5. IR (film, cm⁻¹): ν = 2934 (s), 2886 (m), 2859 (s), 1498 (w), 1473 (m), 1383 (m), 1373 (m), 1363 (m), 1271 (m), 1238 (m), 1210 (m), 1194 (m), 1142 (vs), 1121 (s), 1104 (s), 1078 (s), 1041 (vs), 1015 (s), 987 (s), 967 (m), 940 (m), 903 (m), 886 (m), 871 (m), 848 (m), 826 (m), 796 (m), 772 (m), 748 (m), 735 (m), 717 (m), 698 (m), 651 (m), 606 (w). HRMS: calc. for C₂₉H₄₄O₈SiNa [M+Na]⁺ 571.2698; found: 571.2683.