Supporting Information for: Development and Comparison of Substrate Scope of Pd-Catalysts for the Aerobic Oxidation of Alcohols

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**General Considerations:**

The alcohols used as substrates, HOAc, and Bu₄NOAc were purchased and used as received.¹ [Pd(IiPr)Cl₂]₂ and ¹³ were prepared according to literature methods. PhCH₃ used as solvent was dried before use by passing through a column of activated alumina.⁴ THF was dried by distilling from sodium benzophenone ketyl. CH₂Cl₂ and triethylamine were dried by distilling from CaH₂ before use. The 3Å molecular sieves were powdered and activated by putting under vacuum in a flask and heating with a Bunsen burner. GC conversions for reactions with < 99% conversion were determined relative to undecane or tetradecane as internal standard. GC analysis was performed with a GC equipped with a HP-5 methyl siloxane column and HP-Chiral permethylated β-cyclodextrin column. HPLC analysis was performed using a HPLC equipped with a (R,R) Whelk-O 1 column. ¹H-NMR spectra were obtained at 300 MHz and referenced to the CHCl₃ singlet at 7.27 ppm, and ¹³C-NMR spectra were obtained at 75 MHz and referenced to the center line of the CDCl₃ triplet at 77.23 ppm. All melting points are uncorrected and were recorded on an Electrothermal Melting Point apparatus. IR spectra were recorded using a FTIR instrument.

Standard operating procedures for in situ IR are as follows. For each reaction, background was measured and probe cleaned properly. For each alcohol being monitored, product formation was observed by recording the absorbance at maximum peak height of the carbonyl stretch of the resulting ketone or aldehyde related to a baseline point. The absorbances were converted to concentration units by constructing calibration curves of the products in each respective solvent to determine the extinction coefficient. The apparatus used was a large glass Schlenk tube with jacketed neck for probe insertion and side arm for attachment of condenser fitted with oxygen filled balloon.

**Preparation of Starting Materials**

Alcohols 7a,⁵ 7b,⁶ 7c,⁷ 9a,⁸ 9b,⁹ 9c,¹⁰ 9d,¹¹ and 9e,¹² were made following literature preparations.

*Prep of 1-benzyloxy-3-butanol (7d):* In a flame dried 250 mL round bottom flask equipped with a stir bar was added 5.4 g of 1-benzyloxy-3-butanone (30 mmol, 1 equiv). The ketone was dissolved in 38 mL of MeOH, cooled to 0 °C, and 1.51 g of NaBH₄ (40 mmol, 1.3 equiv) was added in portions over 15 minutes. The stirred mixture was allowed to slowly warm to room temperature over 4 hours. The reaction mixture was diluted in 250 mL of diethyl ether and washed twice with 50 mL of 1M HCl and once with water. The organic layer was dried over MgSO₄, filtered and solvent removed in vacuo to yield 4.95g of a clear oil (92% yield). Purity confirmed by NMR.¹³

*Prep of 1-tert-butyldimethylsilyloxy-2-ethyl-3-hexanol (mixture of isomers) (7e):* In a flame dried 100 mL round bottom flask equipped with a stir bar was added 1.462 g of a mixture of isomers of 2-ethyl-1,3-hexanediol (10 mmol, 1 equiv.), 244 mg dimethylamino pyridine (2 mmol, 0.2 equiv.), 2.8 mL triethylamine (20 mmol, 2 equiv.), and 20 mL CH₂Cl₂ under nitrogen. The mixture was cooled to -78 °C and a solution of...
1.538 g TBDMS-Cl (10.2 mmol, 1.02 equiv.) dissolved in 10 mL CH₂Cl₂ was added dropwise and the mixture was allowed to warm to rt slowly and stirred overnight. The reaction mixture was diluted in ca. 150 mL of diethyl ether and washed twice with 30 mL of water and twice with 30 mL of saturated NH₄Cl. The organic layer was collected and dried over MgSO₄, filtered, and solvent removed in vacuo. The product was purified by column chromatography using 8% EtOAc/hexanes (Rf=0.35 with 10% EtOAc/hexanes) to yield 2.2 g of a clear oil (85% yield).

Analytical Data: IR: 3499, 2957, 2930, 2874, 2859, 1471, 1463, 1255, 1084; ¹H-NMR (CDCl₃): δ 0.05-0.09 (m, 6H), δ 0.87-0.97 (m, 15H), δ 1.27-1.62 (bm, 7H), δ 3.31-3.98 (bm, 4H); ¹³C-NMR (CDCl₃): δ –5.5, -5.49, -5.43, 12.0, 12.5, 14.4, 14.5, 17.8, 18.3, 19.3, 19.7, 21.7, 26.0, 36.0, 38.2, 45.7, 46.1, 64.7, 65.6, 74.6, 75.2; HRMS (C.I.) m/z (MH⁺) calcd. 261.2250 obsd. 261.2260.

Prep of 3-trityloxy-1-butanol (7f): In a 10 mL flame dried round bottom flask equipped with a stir bar was added 500 mg of ethyl-3-hydroxybutyrate (3.78 mmol, 1 equiv) under nitrogen. This was dissolved in 8 mL of CH₂Cl₂ followed by the addition of 790 µL of triethylamine, 23.1 mg of dimethylaminopyridine, and 1.107 g of tritylchloride and the reaction mixture was refluxed for 48 hrs under nitrogen. The mixture was diluted with 100 mL of diethyl ether and washed with 25 ml H₂O, 3X with 25 mL saturated NH₄Cl, and 25 mL brine. The ether layer was dried over Na₂SO₄, filtered, and solvent removed in vacuo. The crude reaction mixture was dissolved in 5 mL of THF and added dropwise to a solution of 266 mg LAH (7 mmol, 2 equiv.) in 15 mL of THF at 0 °C. The reaction mixture was allowed to slowly warm to room temperature and quenched with a 1.5:1 Na₂SO₄-10H₂O:celite mixture, filtered through a pad of celite, and solvent removed in vacuo. The product was purified by recrystallization by slow evaporation from ca. 1:10 ether:hexanes to yield 757 mg of a white solid (65% yield).

Analytical Data: m.p.=90-92 °C; IR (KBr): 3223, 1594, 1488, 1446, 1377, 1035, 1026; ¹H-NMR (CDCl₃): δ 1.09 (d, J=6.3, 3H), δ 1.45-1.55 (m, 2H), δ 2.14 (bs, 1H), δ 3.51-3.63 (m, 1H), δ 3.71-3.88 (m, 2H) δ 7.77-7.39 (m, 9H), δ 7.52-7.62 (m, 6H); ¹³C-NMR (CDCl₃): δ 21.5, 39.4, 60.1, 69.3, 87.3, 127.2, 127.9, 129.1, 145.1; HRMS (E.I.) m/z (M)⁺ calcd. 332.1776 obsd. 332.1774.

Prep of 1,6-heptanediol (14): In a flame dried 100 mL round bottom flask equipped with a stir bar was added 900 mg of LAH (23.6 mml, 3.4 equiv.) and 30 mL of THF. The mixture was cooled to 0 °C and a solution of 1.0 g 5-acetylvaleric acid in 10 mL of THF was added dropwise. The mixture was allowed to warm to room temperature and quenched with the addition of 1.5:1 Na₂SO₄-10H₂O:celite. The solutions was then filtered through a pad of celite, solvent removed in vacuo and purified by column chromatography using 5% MeOH/DCM (Rf=0.15 with 5 % MeOH/DCM) to yield 0.773 g of a viscous oil (85% yield). Purity confirmed by NMR.
Oxidations Using Pd(OAc)$_2$/TEA

**Benzylic, secondary aliphatic, and cyclic allylic alcohols:** To a 25 mL round bottom flask equipped with a stir bar was added 6.7 mg Pd(OAc)$_2$ (0.03 mmol, 0.03 equiv.) and 200 mg of powdered, freshly activated 3Å molecular sieves. To this was added 0.5 mL THF, 2.83 mL of toluene, and 8.4 µL of TEA (0.06 mmol, 0.06 equiv). A three-way joint fitted with a balloon of O$_2$ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir **vigorously** for ca. 30 minutes at room temperature under O$_2$. At this time, 1 mmol of alcohol was added and the reaction stirred **vigorously** at room temperature under a balloon of O$_2$. The reaction progress was monitored by GC. After 12 hrs, the reaction mixture was placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The ether was removed **in vacuo** to yield the desired carbonyl product. For alcohols with incomplete oxidation, the desired carbonyl product was isolated via column chromatography using mixtures of diethyl ether/hexanes as the eluting solvent. Purity of carbonyl products confirmed by NMR.

This procedure was used for the following alcohols: 3a,b,e-h,j-n, 5a-d,j, and 18.

**Modifications:**
- For alcohol 3f conversion was measured by $^1$H-NMR.
- For alcohol 5k conversion was measured by GC using undecane as the internal standard.
- For alcohols 7a, 7d, and 9b: 9.0 mg Pd(OAc)$_2$ (0.04 mmol, 0.04 equiv.) and 11.2 µL of TEA (0.08 mmol, 0.08 equiv) were used with the above procedure. For 9b, conversion was measured by GC using undecane as the internal standard.
- For alcohols 7b, 7c, 7e, 9a, 9c, and 9e 11.2 mg Pd(OAc)$_2$ (0.05 mmol, 0.05 equiv.) and 13.9 µL of TEA (0.10 mmol, 0.10 equiv) were used with the above procedure.

**30 mmol scale oxidation:** In a 500 mL round bottom flask equipped with a stir bar was added 270 mg of Pd(OAc)$_2$ (1.2 mmol, 0.04 equiv.) and 6 g of powdered, freshly activated 3Å molecular sieves. To this was added 70 mL of toluene, 15 mL THF, and 0.335 mL TEA (2.4 mmol, 0.08 equiv.). A three-way joint fitted with a balloon of O$_2$ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir **vigorously** for ca. 30 minutes at room temperature under O$_2$. A mixture of 5.41 g of 7d dissolved in 15 mL of toluene was added to the reaction flask and allowed to stir **vigorously** at room temperature under an O$_2$ balloon for 14 hrs. The reaction mixture was evaporated **in vacuo** down to ca. 30 mL, placed on a pad of silica, washed with 150 mL of hexanes then eluted with 200 mL of diethyl ether. The ether was collected and solvent removed **in vacuo** to yield 5.35 g of a light yellow oil (97% yield).

**Primary aliphatic alcohols and myrtenol:** To a 50 mL round bottom flask equipped with a stir bar was added 6.7 mg Pd(OAc)$_2$ (0.03 mmol, 0.03 equiv.) and 250 mg of powdered, freshly activated 3Å molecular sieves. To this was added 2.6 mL THF, 9.4
mL of toluene, 1.0 mL of 0.01 M Bu₄NOAc/toluene (0.01 mmol, 0.01 equiv), and 25 µL of TEA (0.18 mmol, 0.18 equiv). A three-way joint fitted with a balloon of O₂ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir **vigorously** for ca. 30 minutes at room temperature under O₂. At this time, 1 mmol of alcohol was added and the reaction stirred **vigorously** at room temperature under a balloon of O₂. The reaction progress was monitored by GC. After 12-18 hrs, the reaction mixture was placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The ether was removed **in vacuo** to yield the desired carbonyl product. For alcohols with incomplete oxidation, the desired carbonyl product was isolated via column chromatography using mixtures of diethyl ether/hexanes as the eluting solvent. Purity confirmed of carbonyl products by NMR.

This procedure was used with alcohol 5g.

Modifications:
- For 5l, conversion was measured by GC using undecane as the internal standard.
- For alcohol 7g: 9.0 mg Pd(OAc)$_2$ (0.04 mmol, 0.04 equiv.) and 33.5 µL of TEA (0.24 mmol, 0.24 equiv) along with undecane as the internal standard were used with the above procedure.
- For alcohol 7f and 9d: 11.2 mg Pd(OAc)$_2$ (0.05 mmol, 0.05 equiv.) and 20.9 µL of TEA (0.15 mmol, 0.15 equiv) were used with the above procedure.
- For alcohol 11 (Table 11, entry 1): 11.2 mg Pd(OAc)$_2$ (0.05 mmol, 0.05 equiv.) and 20.9 µL of TEA (0.15 mmol, 0.15 equiv) were used with the above procedure. The ratio of 12:13 was calculated using GC with a response factor of 1.3.

**Oxidation of 1,6-heptane diol (14): Conditions for primary alcohols:** In a 5 mL two-necked round bottom flask equipped with a stir bar was added 9.9 mg (0.075 mmol, 1 equiv.) of the diol along with 20 mg of freshly activated, crushed 3Å molecular sieves. To this was added 0.71 mL toluene, 0.2 mL THF, 0.070 mL of 0.011M Bu₄NOAc in toluene (0.00075 mmol, 0.01 equiv.), and 1.9 µL TEA (0.00135 mmol, 0.18 equiv.). A three-way joint fitted with a balloon of O₂ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir **vigorously** for ca. 30 minutes at room temperature under O₂. At this time 0.090 mL of 0.025M Pd(OAc)$_2$ in toluene (0.00225 mmol, 0.03 equiv.) and the reaction stirred **vigorously**. The reaction progress was monitored by GC. Products were identified using GC/MS and retention times by GC using a 100-220 °C, 20 °C/min ramp were: 14=4.94 min., 15=3.88 min., 16=3.48 min., 17=3.38 min.

**Conditions for secondary alcohols:** In a 5 mL two-necked round bottom flask was added 39.7 mg (0.3 mmol, 1 equiv.) of the diol along with 60 mg of freshly activated, crushed 3Å molecular sieves. To this was added 0.65 mL toluene, 0.15 mL THF, and 2.5 µL TEA (0.018 mmol, 0.06 equiv.). A three-way joint fitted with a balloon of O₂ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir vigorously for ca. 30 minutes at room temperature under O₂. At this time a solution
of 2.0 mg Pd(OAc)$_2$ (0.009 mmol, 0.03 equiv.) in 0.2 mL of toluene was added and the reaction was monitored by GC.

**Oxidation Screen of Methylcyclohexanols (20-22):** To three individual 5 ml two-necked round bottom flasks equipped with a stir bar was added 2.0 mg Pd(OAc)$_2$ (0.009 mmol, 0.03 equiv.) and 60 mg of freshly activated, crushed 3Å molecular sieves. The flasks were attached to a four neck cow. To each flask was added 0.55 mL toluene, 0.15 mL THF and 2.5 µL of TEA (0.018 mmol, 0.06 equiv.). A three-way joint fitted with a balloon of O$_2$ was attached and the apparatus was evacuated and refilled with oxygen three times then allowed to stir vigorously for ca. 30 minutes at room temperature under O$_2$. At this time a solution of 34.3 mg alcohol and 4 µL undecane internal standard dissolved in 0.3 mL of toluene was added and the reactions stirred vigorously at room temperature under O$_2$.

For 2-methylcyclohexanol (20) the conversion and ratio of cis:trans was measured using GC. Cis and trans isomers were identified by comparing NMR of authentic material with NMR of purchased mixture. Starting ratios for NMR were identical to GC. For 3 and 4-methylcyclohexanol (21 and 22) the conversion was measured using GC and the cis:trans ratio was measured by $^1$H-NMR. The cis and trans isomers were identified by comparing the NMR of the mixture to NMR’s of authentic material.

**Oxidations Using Pd(IIPr)(OAc)$_2$(H$_2$O)**

**Benzylic and secondary allylic alcohols:** In a 10 mL round bottom flask equipped with a stir bar was added 3.2 mg Pd(IIPr)(OAc)$_2$(H$_2$O) (0.005 mmol, 0.005 equiv.) and 150 mg of powdered, freshly activated 3Å molecular sieves. To this 0.8 mL of toluene and 0.2 mL of 0.1M AcOH/toluene (0.02 mmol, 0.02 equiv.) was added followed by 1 mmol of alcohol. The flask was attached to a reflux condenser. A three-way joint fitted with a balloon of O$_2$ was attached and the flask was evacuated and refilled with oxygen three times and stirred vigorously for ca. 10 minutes then placed in a 60 °C oil bath. The reaction progress was monitored by GC. After completion, the reaction mixture was cooled to ambient temperature and placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The diethyl ether was removed in vacuo to yield the desired carbonyl product. For alcohols with incomplete oxidation, the desired carbonyl product was isolated via column chromatography using mixtures of diethyl ether/hexanes as the eluting solvent. Purity of carbonyl products confirmed by NMR.

This procedure was used for the following alcohols: 3a, 3c, 3j, 3f, 3m, 3n, 5i, and 5j. For 3k conversion was measured by GC using tetradecane as the internal standard. For 3f, 5i, and 5j, conversion was measured using $^1$H-NMR.

Modification:
• For alcohols 3k, 9a-c, and 9e: 6.31 mg Pd(IiPr)(OAc)_2(H_2O) (0.01 mmol, 0.01 equiv) was used with the above procedure. For 9a and 9e conversion was measured by GC using undecane as the internal standard. For 9c conversion was measured by ^1H-NMR.

Secondary aliphatic alcohols and allylic alcohols: In a 10 mL round bottom flask equipped with a stir bar was added 3.2 mg Pd(IiPr)(OAc)_2(H_2O) (0.005 mmol, 0.005 equiv.) and 150 mg of powdered, freshly activated 3Å molecular sieves. To this 0.9 mL of toluene and 0.1 mL of 0.1M AcOH/toluene (0.01 mmol, 0.01 equiv.) was added followed by 1 mmol of alcohol. The flask was attached to a reflux condenser. A three-way joint fitted with a balloon of O_2 was attached and the flask was evacuated and refilled with oxygen three times and stirred vigorously for ca. 10 minutes then placed in a 60 °C oil bath. The reaction progress was monitored by GC. After completion, the reaction mixture was cooled to ambient temperature and placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The diethyl ether was removed in vacuo to yield the desired carbonyl product. For alcohols with incomplete oxidation, the desired carbonyl product was isolated via column chromatography using mixtures of diethyl ether/hexanes as the eluting solvent. Purity of carbonyl products confirmed by NMR.

This procedure was used with the following alcohols: 5a, 5e, 7c, 7d, 7e, and 11. For 7d conversion was measured by GC using undecane internal standard. For 7e and 7e conversion was measured by NMR.

Modification
• For alcohols 7a, 7b.: 6.31 mg Pd(IiPr)(OAc)_2(H_2O) (0.01 mmol, 0.01 equiv) was used with the above procedure using GC to measure conversion with undecane as the internal standard.

Primary aliphatic and allylic alcohols: In a 50 mL round bottom flask equipped with a stir bar was added 4.7 mg Pd(IiPr)(OAc)_2(H_2O) (0.0075 mmol, 0.0075 equiv.), 15.1 mg Bu_4NOAc (0.05 mmol, 0.05 equiv.), and 200 mg of powdered, freshly activated 3Å molecular sieves. To this 10.0 mL of toluene was added followed by 1 mmol of alcohol. The flask was attached to a reflux condenser. A three-way joint fitted with a balloon of O_2 was attached and the flask was evacuated and refilled with oxygen three times and stirred vigorously for ca. 10 minutes then placed in a 60 °C oil bath. The reaction progress was monitored by GC. After completion, the reaction mixture was cooled to ambient temperature and placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The diethyl ether was removed in vacuo to yield the desired carbonyl product. For alcohols with incomplete oxidation, the desired carbonyl product was isolated via column chromatography using mixtures of diethyl ether/hexanes as the eluting solvent. Purity of carbonyl products confirmed by NMR.
This procedure was used with the following alcohols: 3f, 5k, 5g, 5h, 7g, 9d, 11 and 14. For 5k, 7g and 11 conversions were measured by GC using undecane as the internal standard. For 9d conversion was measured by \textsuperscript{1}H-NMR. For 14, conversion and ratios of products were measured by GC without internal standard due to solubility issues.

Modification:
- For alcohols 11 (Table 11, entry 11): the above procedure was used. The ratio of 12:13 was calculated using GC with a response factor of 1.3.
- For alcohols 5l and 7f: 3.2 mg 1 (0.005 mmol, 0.005 equiv.) was used with the above procedure. For 5l conversion was measured using undecane as the internal standard. For 7f conversion was measured using \textsuperscript{1}H-NMR.

**In-Situ Prepared Catalyst (Table 3, entry 2):**

In a 25 mL flame dried Schlenk flask equipped with a stir bar was added 2.3 mg of Pd(OAc)$_2$ (0.01 mmol, 0.005 equiv.), 6.2 mg of iPr-HBF$_4$ salt (0.013 mmol, 0.0065 equiv.), 1.6 mg of KOtBu (0.014 mmol, 0.007 equiv.) and 250 mg of powdered, activated 3Å molecular sieves were added. To this was added 0.8 mL of THF. The flask was placed under N$_2$ and placed in an oil bath at 60 °C. The mixture was stirred for 45 minutes, cooled to room temperature, and 2.3 µL of HOAc (0.04 mmol, 0.02 equiv) and 3.2 mL of toluene were added by syringe. The flask was attached to a reflux condenser. A three-way joint fitted with a balloon of O$_2$ was attached and the flask was evacuated and refilled with oxygen three times. 241 µL of sec-phenethyl alcohol (3a), (2.0 mmol, 1 equiv.) was added and the flask is placed in an oil bath at 60 °C. The reaction progress was monitored by GC to determine the % conversion.

**0.1 mol % catalyst (Table 3, entry 4):**

In a 10 ml flask equipped with a stir bar was added 0.8 mg of Pd(iPr)(OAc)$_2$-(H$_2$O) (0.0013 mmol, 0.001 equiv.) and 188 mg of powdered, activated 3Å molecular sieves were added. To this 2.5 mL of PhCH$_3$ and 1.4 µL of HOAc (0.025 mmol, 0.02 equiv) were added followed by 155 µL (1.25 mmol, 1.0 equiv) of alcohol 3c. The flask was attached to a reflux condenser. A three-way joint fitted with a balloon of O$_2$ was attached and the flask was evacuated and refilled with oxygen three times and stirred vigorously for ca. 10 minutes then placed in a 60 °C oil bath. The reaction progress was monitored by GC to determine % conversion.

**Oxidations Using Air:**

*Benzylic Substrates:* In a 10 ml flask equipped with a stir bar was added 1.6 mg of 1 (0.0025 mmol, 0.005 equiv.) and 100 mg of powdered, activated 3Å molecular sieves were added. To this 1.0 mL of PhCH$_3$ and 1.1 µL of HOAc (0.02 mmol, 0.04 equiv) were added followed by 0.5 mmol (1.0 equiv) of the alcohol. The flask was attached to a reflux condenser and the reflux condenser was left open to the air. The reaction was
placed in an oil bath at 60 °C and progress monitored by GC to determine the % conversion. For substrate 3b, an isolated yield was obtained by allowing the reaction to cool to room temperature and loading the reaction mixture directly on a silica gel plug. The plug is first washed with pentane to elute PhCH₃ and then solvent is switched to Et₂O to elute the ketone product. Removal of the solvent in vacuo gave the product.

This procedure was used with the following alcohols: 3b, 3j, and 3l.

**Large Scale Reaction:** In a 100 ml flask equipped with a stir bar was added 25.8 mg of 1 (0.040 mmol, 0.005 equiv.) and 1.3 g of powdered, activated 3Å molecular sieves were added. To this, 16.4 mL of PhCH₃ and 23 µL of HOAc (0.40 mmol, 0.05 equiv) were added, followed by 0.994 g (8.15 mmol, 1.0 equiv) of sec-phenethyl alcohol, 3a. The flask was attached to a reflux condenser, and the reflux condenser was left open to the air. The reaction was placed in an oil bath at 60 °C. The reaction progress was monitored by GC to determine the % conversion. After 14 h, the reaction was allowed to cool to room temperature and loaded directly on a silica gel plug. The plug is first washed with pentane to elute PhCH₃ and then solvent is switched to Et₂O to elute the ketone product. Removal of the solvent in vacuo gave 0.948 g of acetophenone as an oil.

**Secondary Aliphatic Substrates:** In a 10 ml flask equipped with a stir bar was added 1.6 mg of 1 (0.0025 mmol, 0.005 equiv.) and 100 mg of powdered, activated 3Å molecular sieves were added. To this, 1.0 mL of PhCH₃ and 0.6 µL of HOAc (0.01 mmol, 0.02 equiv) were added by syringe, followed by 0.5 mmol (1.0 equiv) of the alcohol. The flask was attached to a reflux condenser and the reflux condenser was left open to the air. The reaction was placed in an oil bath at 60 °C. The reaction progress was monitored by GC to determine the % conversion. This procedure was used with 5e.

**Oxidation of Methyl cyclohexanols (20-22):** To three individual 5 mL two-necked round bottom flask equipped with a stir bar was added 1.6 mg of 1 (0.0025 mmol, 0.005 equiv.) and 75 mg of freshly activated, crushed 3Å molecular sieves. To this was added 0.65 mL of toluene and 0.05 mL of 0.1M AcOH in toluene (0.005 mmol, 0.01 equiv.). A mixture of 57.1 mg alcohol (0.5 mmol, 1 equiv.) and 8 µL of undecane dissolved in 0.3 mL of toluene was added. A three-way joint fitted with a balloon of O₂ was attached and the flask was evacuated and refilled with oxygen three times then allowed to stir vigorously for ca. 10 minutes then placed in a 60 °C oil bath.

For 2-methylcyclohexanol (20) the conversion and ratio of cis:trans was measured using GC.

For 3 and 4-methylcyclohexanol (21 and 22) the conversion was measured using GC and cis:trans ratio was measured by ¹H-NMR.
Pd(IiPr)(OPiv)$_2$ Oxidations

To a 25 mL round bottom flask equipped with a stir bar was added 7.2 mg \textit{2} (0.01 mmol, 0.01 equiv.) and 250 mg of powdered, freshly activated 3Å molecular sieves. To this 2.45 mL of toluene and 0.05 mL 0.1M PivOH/toluene (0.005 mmol, 0.005 equiv.) was added. A three-way joint fitted with a balloon of air was attached. To the catalyst mixture was added 1 mmol of alcohol and the reaction was stirred \textit{vigorously}. The reaction progress was monitored by GC. After completion, the reaction mixture was cooled to ambient temperature and placed directly on a plug of silica, washed with pentane to remove toluene, and eluted with diethyl ether. The diethyl ether was removed \textit{in vacuo} to yield the desired carbonyl product.

This procedure was used with the following alcohols: \textit{3d}.

Modifications:
- For alcohols \textit{3a, 3c, 3i, 3k, 5a, 5e, 5i, 5k, 5l, 7a, 7b, 7d, 9a, 9b}, and \textit{9e} the above procedure was used with conversions measured by GC using undecane as internal standard.
- For alcohols \textit{3f, 7e, 7e, and 9e} the above procedure was used with conversions measured by $^1$H-NMR.
- For 2-methylcyclohexanol (\textit{20}) the conversion and ratio of \textit{cis:trans} was measured using GC.
- For 3 and 4-methylcyclohexanol (\textit{21 and 22}) the conversion was measured using GC and \textit{cis:trans} ratio was measured by $^1$H-NMR.

Analytical Data for Aldehyde and Ketone Products

\textit{1-trityloxy-3-butanone (8c)}: white solid, m.p.=89-91 °C; IR (KBr): 3085, 3056, 3032, 2954, 2926, 2878, 1712, 1490, 1448, 1359, 1177, 1070; $^1$H-NMR (CDCl$_3$): $\delta$ 2.17 (s, 3H), 2.70 (t, J=6.4 Hz, 2H), 3.42 (t, J=6.4 Hz, 2H), 7.22-7.39 (m, 9H), 7.42-7.50 (m, 6H); $^{13}$C-NMR (CDCl$_3$): $\delta$ 30.5, 44.3, 59.5, 87.0, 127.2, 128.0, 128.8, 144.1, 207.9; HRMS (E.I.) m/z (M$^+$) calcd. 330.1620 obsd. 330.1620.

\textit{3-(tert-Butyl-dimethyl-silanyloxymethyl)-heptan-4-one (8e)}: clear oil, IR: 2959, 2930, 2877, 2858, 1715, 1257, 1097; $^1$H-NMR (CDCl$_3$): $\delta$ 0.02 (d, J=5.1, 6H), 0.82-0.95 (m, 15H), 1.3-1.48 (m, 1H), 1.48-1.68 (m, 3H), 2.33-2.59 (m, 2H), 2.59-2.74 (m, 1H), 3.58-3.77 (m, 2H); $^{13}$C-NMR (CDCl$_3$): $\delta$ –5.4, 12.1, 14.0, 16.8, 18.4, 21.5, 26.0, 46.4, 56.2, 64.7, 214.3; HRMS (C.I.) m/z (MH$^+$) calcd. 259.2093 obsd. 259.2082.

\textit{3-trityloxy-butanal (8f)}: clear, viscous oil, IR: 2959, 2930, 2877, 2858, 1712, 1257, 1097; $^1$H-NMR (CDCl$_3$): $\delta$ 0.02 (d, J=5.1, 6H), 0.82-0.95 (m, 15H), 1.3-1.48 (m, 1H), 1.48-1.68 (m, 3H), 2.33-2.59 (m, 2H), 2.59-2.74 (m, 1H), 3.58-3.77 (m, 2H); $^{13}$C-NMR (CDCl$_3$): $\delta$ –5.4, 12.1, 14.0, 16.8, 18.4, 21.5, 26.0, 46.4, 56.2, 64.7, 214.3; HRMS (E.I.) m/z (M$^+$) calcd. 330.1620 obsd. 330.1610.
1-Phenyl-2-trityloxy-ethanone (10c): white solid, m.p.=106-108; IR (KBr): 3083, 3057, 3020, 2902, 2835, 1699, 1490, 1448, 1220, 1119; \(^1\)H-NMR (CDCl\(_3\)): \(\delta\) 4.45 (s, 2H), 7.25-7.47 (bm, 11H), 7.51-7.61 (m, 7H), 7.78-7.85 (m, 2H); \(^1\)C-NMR (CDCl\(_3\)): \(\delta\) 67.9, 87.6, 127.5, 128.19, 128.23, 128.7, 128.8, 133.4, 135.5, 143.6, 495.8; HRMS (E.I.) m/z (M\(^+\)) calcd. 378.1620 obsd. 378.1600.

2-tert-Butoxycarbonylamino-3-methyl-butyric acid 2-tert-butoxycarbonylamino-3-methyl-butylic acid ester (13): white solid, m.p.=123-125 °C; IR (KBr): 3358, 2967, 2937, 2874, 1741, 1690, 1682, 1528, 1365, 1249, 1159; \(^1\)H-NMR (CDCl\(_3\)): \(\delta\) 0.85-1.01 (m, 12H), 1.41-.48 (M, 18H), 1.73-1.89 (m, 1H), 2.02-2.22 (m, 1H), 3.57-3.77, (m, 1H), 3.99-4.39 (m, 3H), 4.61 (bd, J=9.3, 1H), 5.02 (bd, J=9.3, 1H); \(^1\)C-NMR (CDCl\(_3\)): \(\delta\) 17.7, 18.7, 19.2, 19.6, 28.53, 28.57, 29.9, 31.4, 54.9, 58.8, 65.6, 79.6, 80.0, 155.8, 155.9, 127.7; HRMS (C.I): m/z (MH\(^+\)) calcd. 403.2808 obsd. 403.2798

### Chiral Separations:

<table>
<thead>
<tr>
<th>Substrate</th>
<th>GC/HPLC</th>
<th>Column</th>
<th>Method</th>
<th>Retention Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTr OH</td>
<td>HPLC</td>
<td>Whelk-O</td>
<td>1% IPA/Hexanes</td>
<td>10.8 (S): 11.7</td>
</tr>
<tr>
<td>OTr</td>
<td>HPLC</td>
<td>Whelk-O</td>
<td>1% IPA/Hexanes</td>
<td>7.4 : 10.2 (S)</td>
</tr>
<tr>
<td>N-boc-norephedrine</td>
<td>HPLC</td>
<td>Whelk-O</td>
<td>2% IPA/Hexanes</td>
<td>12.2 : 14.2 (1S, 2R)</td>
</tr>
<tr>
<td>N-Boc-valinol</td>
<td>GC</td>
<td>HP-Chiral</td>
<td>100 isothermal</td>
<td>96.0 : 99.8 (D)</td>
</tr>
<tr>
<td>N-Boc-valinal</td>
<td>GC</td>
<td>HP-Chiral</td>
<td>100 isothermal</td>
<td>29.1 : 30.0 (D)</td>
</tr>
</tbody>
</table>

1 Even though Bu\(_4\)NOAc is hygroscopic, drying the Bu\(_4\)NOAc by azeotroping with PhCH\(_3\) before use had no noticeable effect.
2 Jensen, D. R.; Sigman, M. S. *Org. Lett.* **2002**, 5, 63-65


See Sigma-Aldrich website for NMR identification of cis and trans 20 and 22.


acetophenone

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: secphen14-15-02
INOVA-500 "nmr-sun"

Pulse 45.0 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 300.0771356 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 0 sec
1-(4-methoxy-phenyl)-ethanone

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: pMeO-secphen24-12-02
INOVA-500 "nmr-sun"

Pulse 45.0 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 300.0771354 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 0 sec
p-Methoxy benzaldehyde

Pulse Sequence: s2pul
m-Methoxy benzaldehyde
Pulse Sequence: s2pul
keck's benzillic alchol 5-13-02

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: keckbenzalc5-13-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927890 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 16 sec
p-methylsulfanyl-benzaldehyde

Pulse Sequence: s2pul
1-(4-nitro-phenyl)-ethanone

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: pNO25-9-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927885 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 16 sec

![NMR Spectrum of 1-(4-nitro-phenyl)-ethanone](image-url)
4-chloro-benzaldehyde

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: pC8-2-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
20 repetitions
OBSERVE H1, 299.6927887 MHz
DATA PROCESSING
FT size 32768
Total time 2 min, 32 sec

![NMR Spectrogram of 4-chloro-benzaldehyde]
STANDARD 1H OBSERVE

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: mCF34-18-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927880 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 16 sec
2,2-dimethyl-1-phenyl-propan-1-one

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: tBu4-24-02
INOVA-500 "nmr-sun"

Pulse 45.0 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 300.0771354 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 0 sec
1-indanone

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: 1-indanone5-8-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927883 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 16 sec

\[ \text{1-indanone} \]

\[ \text{Pulse Sequence: s2pul} \]
\[ \text{Solvent: CDCl3} \]
\[ \text{Ambient temperature} \]
\[ \text{File: 1-indanone5-8-02} \]
\[ \text{INOVA-500 "nmr-sun"} \]

\[ \text{Relax. delay 1.000 sec} \]
\[ \text{Pulse 36.6 degrees} \]
\[ \text{Acq. time 3.744 sec} \]
\[ \text{Width 4000.0 Hz} \]
\[ \text{16 repetitions} \]
\[ \text{OBSERVE H1, 299.6927883 MHz} \]
\[ \text{DATA PROCESSING} \]
\[ \text{FT size 32768} \]
\[ \text{Total time 1 min, 16 sec} \]
2-decanone
Pulse Sequence: s2pul

S
26

6a
2-methyl-2-cyclohexan-1-one

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: 2MecyanolB-2-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
32 repetitions
OBSERVE H1, 299.6927887 MHz
DATA PROCESSING
FT size 32768
Total time 2 min, 32 sec
2-adamantanone

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: adamantanone5-2-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927891 MHz
DATA PROCESSING
FT size 32768
Total time 1 min, 16 sec
hexahydro-isobenzoruan-1-one

Pulse Sequence: s2pul
Solvent: CDCl₃
Ambient temperature
File: diolproduct8-2-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
16 repetitions
OBSERVE H1, 299.6927887 MHz
DATA PROCESSING
FT size 32768
Total time 2 min, 32 sec

![NMR Spectrum]
cyclohexylethanone

Pulse Sequence: s2pul
dodecanal

Archive directory: /home/nmr/vnmr1/vnmrsys/data
Sample directory:

Pulse Sequence: s2pul
stearal

Pulse Sequence: s2pul
cyclohex-1-enyl-ethanone

Pulse Sequence: s2pul
3-methyl-2-cyclohexen-1-one

Pulse Sequence: s2pul
Solvent: CDCl3
Ambient temperature
File: Mecyenone8-2-02
INOVA-500 "nmr-sun"

Relax. delay 1.000 sec
Pulse 36.6 degrees
Acq. time 3.744 sec
Width 4000.0 Hz
28 repetitions
OBSERVE H1, 299.6927887 MHz
DATA PROCESSING
FT size 32768
Total time 2 min, 32 sec
citral

Archive directory: /home/nmr/vnmr1/vnmrsys/data
Sample directory:

Pulse Sequence: s2pul
cinnamaldehyde

Archive directory: /home/nmr/vnmrl/vnmr.sys/data
Sample directory:

Pulse Sequence: s2pul
Solute: CDCl3
Ambient temperature
File: cisaleq9-4-02
UNITY-300 "unity300nmr"

Delay, delay 1.000 sec
Pulse 90.0 degrees
Acq. time 4.000 sec
Width 4480.9 Hz
15 repetitions
Observe 8, 500.07/1.368 MHz
DATA PROCESSING
FT size 61536
Total time 2 min, 40 sec
3-trityloxy-1-butanol

Archive directory: /home/nmr/vnmr1/vnmrsys/data
Sample directory:
Pulse Sequence: s2pul
1-tButyldimethylsilyloxy-3-butanone

Pulse Sequence: s2pul
1-acetoxy-3-butanone
Pulse Sequence: s2pul
1-benzyloxy-3-butanone
Pulse Sequence: s2pul
2-tertButyl-diMethylsilyloxy-1-phenyl-ethanone

Pulse Sequence: s2pul
1-phenyl-2-acetoxy-ethanone

Archive directory: /home/nmr/vnmr1/vnmrsys/data
Sample directory:

Pulse Sequence: s2pul
2-trityloxypropanal

Pulse Sequence: s2pul
Boc-2-amino-1-phenyl-propan-1-one

Pulse Sequence: s2pul