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September 2014: The paragraphs above replace the section "Handling and Disposal of Hazardous Chemicals" in the originally published version of this article. The statements above do not supersede any specific hazard caution notes and safety instructions included in the procedure.

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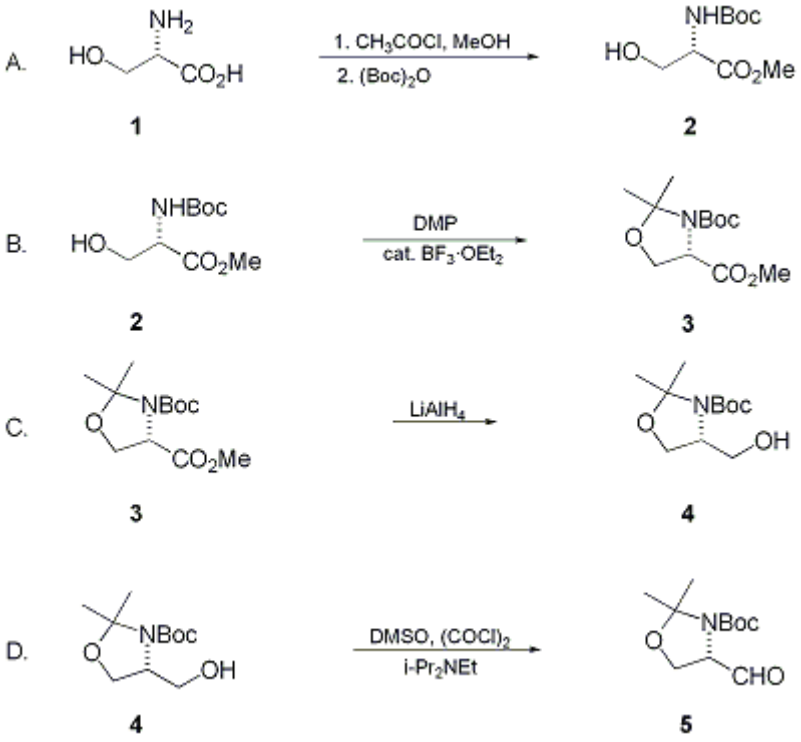
SYNTHESIS OF 1,1-DIMETHYLETHYL (S)-4-FORMYL-2,2-DIMETHYL-3-OXAZOLIDINECARBOXYLATE BY OXIDATION OF THE ALCOHOL

[3-Oxazolidinecarboxylic acid, 4-formyl-2,2-dimethyl-, 1,1-dimethylethyl ester, (S)-]



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Checked by Mark M. Gleason and William R. Roush.

1. Procedure

A. N-[(1,1-Dimethylethoxy)carbonyl]-L-serine methyl ester **(2)** . A 250-mL, three-necked, round-bottomed flask, containing a magnetic stirring bar, is equipped with a dropping funnel, reflux condenser protected from moisture by a calcium chloride-filled drying tube and a rubber septum (Note 1). The dropping funnel is charged with 23 mL of acetyl chloride (Note 2). *Caution! Acetyl chloride is a reactive substance that must be handled in a fume hood* . The flask is charged with 150 mL of methanol (Note 3) and cooled with an ice-water bath under nitrogen. Acetyl chloride is added dropwise over a period of 8 min. The solution is stirred for a further 5 min, then solid 99% (L)-serine, **1**, (12.0 g, 114 mmol, (Note 4)) is added in one portion and the solution is slowly heated to reflux. The reflux is continued for 2 hr, then the solution is allowed to cool to room temperature and the solvent is removed under reduced pressure to give 17.5-17.7 g of crude methyl serinate hydrochloride (98-99% yield) as a white crystalline solid that is used without further purification.

A 500-mL, three-necked, round-bottomed flask, is equipped with a magnetic stirring bar, thermometer, reflux condenser protected from moisture by a calcium chloride-filled drying tube, and a pressure-equalizing dropping funnel that is connected to a nitrogen flow line and is charged with a solution of 97% di-tert-butyl dicarbonate (14.3 g, 63.6 mmol) (Note 5) in tetrahydrofuran (100 mL, (Note 6)). Methyl serinate hydrochloride (10.0 g, 64.3 mmol) is placed in the flask and suspended in tetrahydrofuran (200 mL) and 99% triethylamine (14.0 g, 138 mmol, (Note 7)). The resulting white

suspension is cooled with an ice-water bath and the solution of di-tert-butyl dicarbonate is added dropwise over a period of 1 hr. After 10 min of additional stirring, the ice-water bath is removed and the suspension is stirred overnight (14 hr) at room temperature, then warmed at 50°C for a further 3 hr. The solvent is removed under reduced pressure and the residue is partitioned between diethyl ether (200 mL) and saturated aqueous bicarbonate solution (250 mL). The aqueous phase is extracted with three 150-mL portions of diethyl ether . The combined organic phases are dried with anhydrous sodium sulfate and concentrated under reduced pressure to give 13.4-14.0 g (95-99% crude yield) of N-Boc-L-serine methyl ester as a colorless oil that is used without further purification (Note 8).

B. 3-(1,1-Dimethylethyl) 4-methyl-(S)-2,2-dimethyloxazolidine-3,4-dicarboxylate **(3)** . To a solution of N-Boc-L-serine methyl ester (10.0 g, 45.6 mmol) in acetone (165 mL) is added 2,2-dimethoxypropane (50 mL, 400 mmol) and boron trifluoride etherate ($BF_3 \cdot OEt_2$, 0.35 mL, 2.8 mmol) (Note 9) and (Note 10). The resulting orange solution is stirred at room temperature for 2.5 hr when TLC analysis indicates the reaction to be complete (Note 11). The reaction mixture is treated with 0.9 mL of 99% triethylamine and the solvent is removed under reduced pressure. The residual brown syrup is partitioned between diethyl ether (150 mL) and saturated aqueous sodium bicarbonate solution (250 mL). The aqueous layer is extracted with diethyl ether (2 × 150 mL) and the combined organic phases are dried with anhydrous sodium sulfate and concentrated under reduced pressure (7 mm and 65°C bath temperature) to give 10.4-10.8 g (88-91% crude yield) of oxazolidine methyl ester **3** as a pale yellow oil (Note 12). Analysis of crude **3** by ^{1}H NMR indicates a chemical purity of > 95%. The product can be used without further purification.

C. N-[(1,1-Dimethylethoxy)carbonyl]-N,O-isopropylidene-L-serinol **(4)** . A 250-mL, two-necked, round-bottomed flask is equipped with a magnetic stirring bar, reflux condenser bearing a drying tube and a pressure-equalizing dropping funnel fitted with a rubber septum (Note 1). The flask is charged with 100 mL of tetrahydrofuran and 2.16 g (57.0 mmol) of lithium aluminum hydride (Note 6) and (Note 13). While the suspension in the flask is stirred, a solution of the oxazolidine ester **3** (9.90 g, 38.2 mmol) in tetrahydrofuran (50 mL) is added dropwise over 20 min. The dropping funnel is washed with two 3-mL portions of tetrahydrofuran and the suspension is stirred for an additional 20 min, when TLC analysis shows the complete formation of the alcohol **4** (Note 14). The reaction mixture is cooled with an ice-water bath while 20 mL of a 10% aqueous potassium hydroxide solution is added dropwise over 10 min. *Caution! The reaction is exothermic*. The mixture is stirred for 1 hr at room temperature, then the white precipitate is removed by filtration through a Celite pad and the pad is rinsed with three 30-mL portions of diethyl ether . The combined organic filtrates are washed with 100 mL of aqueous phosphate buffer (pH 7) (Note 15), and the aqueous layer is extracted with diethyl ether (3 × 30 mL). The combined organic phases are dried with anhydrous sodium sulfate and concentrated under reduced pressure to give 8.20-8.48 g (93-96% crude yield) of a pale yellow oil. The crude product that solidifies on cold storage (mp 35-38°C) is used without further purification (Note 16). Analysis of crude alcohol **4** by ^{1}H NMR indicates a chemical purity of > 95%.

D. 1,1-Dimethylethyl (S)-4-formyl-2,2-dimethyl-3-oxazolidinecarboxylate **(5)** . A 250-mL, three-necked, round-bottomed flask, containing a magnetic stirring bar is equipped with a low-temperature thermometer and two equalizing dropping funnels (Note 1). One of these is connected to a nitrogen flow line and is charged with a solution of N-Boc-L-serinol **4** (8.0 g, 34.6 mmol) in methylene chloride (60 mL), the other is charged with a solution of dimethyl sulfoxide (8.10 g, 103.71 mmol) in 10 mL of methylene chloride (Note 17) and (Note 18). The flask is charged with a solution of oxalyl chloride (6.58 g, 51.9 mmol, (Note 19)) in 80 mL of methylene chloride , then cooled to −78°C in a CryoCool bath. *Caution! Oxalyl chloride is a reactive substance that must be handled in a fume hood.* When the solution in the flask is at −78°C, dimethyl sulfoxide is added dropwise over 25 min, while the temperature of the reaction mixture rises to −70°C. At the end of the addition the reaction solution is warmed to −60°C over a period of 20 min, then the N-Boc-L-serinol **4** is added dropwise over 50 min and the reaction temperature rises to −55°C. The dropping funnel is washed with two 5-mL portions of methylene chloride , then charged with a solution of N,N-diisopropylethylamine (36 mL, 200 mmol, (Note 20)) in 5 mL of methylene chloride and the reaction solution is warmed to −45°C over a period of 30 min. N,N-Diisopropylethylamine is added over 5 min, then the reaction flask is removed from the CryoCool bath and allowed to warm to 0°C over 10 min. The reaction solution is transferred to a 500-mL separatory funnel charged with 130 mL of ice-cold 1 M hydrochloric acid solution. The two phases

are separated, the aqueous phase is extracted with methylene chloride (3 × 30 mL), and the combined organic phases are washed with pH 7 aqueous phosphate buffer (4 × 80 mL) (Note 15), then dried with anhydrous sodium sulfate and concentrated under reduced pressure to give 7.89 g (99% crude yield) of the aldehyde **5** as a clear yellow oil (Note 21) and (Note 22). Analysis of crude aldehyde **5** by ^{1}H NMR indicates a chemical purity of > 95%.

2. Notes

1. The glass components of the apparatus were dried overnight in a 150°C oven and allowed to cool in a desiccator over a drying agent before assembly.
2. Acetyl chloride was purchased from the Acros Chimica and distilled before use. The checkers purchased acetyl chloride from Aldrich Chemical Company, Inc. , and used it without purification. *Caution! Acetyl chloride is a reactive substance that must be handled in a fume hood.*
3. Methanol was dried before use by distillation from magnesium methoxide under an atmosphere of nitrogen.
4. L-Serine was purchased from the Acros Chimica or Aldrich Chemical Company, Inc. , and used without purification.
5. Di-tert-butyl dicarbonate was purchased from the Acros Chimica or Aldrich Chemical Company, Inc. , and used without purification.
6. Tetrahydrofuran was dried before use by distillation from sodium metal and benzophenone under an atmosphere of nitrogen.
7. Triethylamine was purchased from the Acros Chimica or Aldrich Chemical Company, Inc. , and used without purification.
8. Submitters report an optical rotation value for crude N-Boc-L-serine methyl ester **2** of $[\alpha]_D$ −19.1° (MeOH, *c* 4.07), very close to that reported by McKillop, et al.[2] (lit.[2] $[\alpha]_D$ −18.9° (MeOH, *c* 5.0)). Checkers report the following data for **2**: $[\alpha]_D^{23}$ 17.0° (MeOH, *c* 4.41); ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.42 (s, 9 H), 3.03 (br s, 1 H), 3.75 (s, 3 H), 3.84 (dd, 1 H, J = 11, 3.3), 3.93 (br d, 1 H, J = 8.1), 4.33-4.36 (m, 1 H), 5.55 (br d, 1 H, J = 7.5) ; ^{13}C NMR (75 MHz, $CDCl_3$) δ: 28.5, 52.7, 55.7, 63.3, 80.2, 155.6, 171.2 ; IR (neat) cm^{-1}: 3400, 1717 . Anal. Calcd for $C_9H_{17}NO_5$: C, 49.31; H, 7.82; N, 6.39. Found C, 49.51; H, 7.86; N, 6.21.
9. Acetone was distilled from potassium permanganate prior to use.
10. 2,2-Dimethoxypropane and boron trifluoride etherate were purchased from Acros Chimica or Aldrich Chemical Company, Inc. , and used without further purification.
11. TLC analysis on silica gel 60F-254 plates eluting with (1:1) cyclohexane-ethyl acetate showed the clean formation of ester **3** with R_f = 0.74 (visualized with 0.3% ninhydrin in (97:3) butanol-acetic acid) at the expense of starting material with R_f = 0.4. The sample of the oxazolidine ester was neutralized with a little triethylamine prior to TLC analysis.
12. Submitters report an optical rotation for the crude oxazolidine methyl ester **3** of $[\alpha]_D$ −54.4° ($CHCl_3$, *c* 1.07), nearly identical to that found by McKillop, et al.[2] [lit.[2] $[\alpha]_D$ −54.0° ($CHCl_3$, *c* 1.3)]. Purification with flash chromatography on silica gel eluting with (85:15) cyclohexane-ethyl acetate gave a product with a maximum rotation of $[\alpha]_D$ −58.3° ($CHCl_3$, *c* 0.86), very close to that reported by Garner, et al.[3 4] (lit.[3,4] −57°). Checkers report the following data for **3**: $[\alpha]_D^{23}$ −53.5° ($CHCl_3$, *c* 1.05); ^{1}H NMR (400 MHz, C_6D_6, 75°C) δ: 1.39 (s, 9 H), 1.54 (br s, 3 H), 1.82 (br s, 3 H), 3.34 (s, 3 H), 3.74 (m, 1 H), 3.80 (dd, 1 H, J = 8.8, 3.2), 4.26 (m, 1 H) ; ^{13}C NMR (100 MHz, C_6D_6, 75°C) δ: 24.7, 25.3, 28.4, 51.6, 59.8, 66.4, 79.9, 95.5, 151.4, 171.3 ; IR (neat) cm^{-1}: 2980, 1759, 1708 . Anal. Calcd for $C_{12}H_{21}NO_5$: C, 55.58; H, 8.16; N, 5.40. Found: C, 55.52; H, 8.29; N, 5.44.
13. Lithium aluminum hydride was purchased from Acros Chimica or Aldrich Chemical Company, Inc. , and used without further purification.
14. TLC analysis on silica gel plates eluting with (7:3) cyclohexane-ethyl acetate showed the clean formation of the alcohol with R_f = 0.24 (visualized with 0.3% ninhydrin in (97:3) butanol-acetic acid) at the expense of the starting material with R_f = 0.55.
15. Checkers used an aqueous NaH_2PO_4/Na_2HPO_4 buffer with a phosphate concentration of ca. 0.5 M.
16. Submitters found the optical rotation of the crude alcohol to be $[\alpha]_D$ −23.9° ($CHCl_3$, *c* 1.0). Purification with flash chromatography on silica gel eluting with (7:3) cyclohexane-ethyl acetate gave a colorless syrup that solidified upon cold storage [mp 45-46°C; $[\alpha]_D$ −26.7° ($CHCl_3$, *c* 1.0)], [lit.[3] mp 38-39°C; $[\alpha]_D$ −24.0° ($CHCl_3$, *c* 1.61)]. Occasionally the compound crystallized at room temperature to give colorless prisms with a maximum mp of 49-51°C. Checkers report the following data for **4**: $[\alpha]_D^{23}$

−26.2° ($CHCl_3$, *c* 0.79); ^{1}H NMR (400 MHz, C_6D_6, 70°C) δ: 1.37 (s, 9 H), 1.43 (br s, 3 H), 1.55 (br s, 3 H), 3.20 (br s, 1 H), 3.48 (m, 1 H), 3.63-3.68 (m, 3 H), 3.87 (m, 1 H) ; ^{13}C NMR (100 MHz, C_6D_6, 70°C) δ: 24.3, 27.3, 28.4, 59.7, 64.0, 65.5, 80.1, 94.1, 153.4 ; IR (neat) cm^{-1}: 3430, 1699, 1380, 1260, 1174, 1050, 848 . Anal. Calcd for $C_{11}H_{21}NO_4$: C, 57.12; H, 9.15; N, 6.00. Found: C, 56.84; H, 9.10; N, 6.06.
17. Methylene chloride was dried before use by distillation over calcium hydride under an atmosphere of nitrogen.
18. Dimethyl sulfoxide was purchased from Acros Chimica or Aldrich Chemical Company, Inc. , and distilled under reduced pressure before use.
19. Oxalyl chloride was purchased from Acros Chimica or Aldrich Chemical Company, Inc. , and distilled under an atmosphere of nitrogen before use. *Caution! Oxalyl chloride is a reactive substance that must be handled in a fume hood.*
20. N,N-Diisopropylethylamine was purchased from Acros Chimica and used without further purification.
21. The optical rotation of the crude aldehyde was $[\alpha]_D$ −89.7° ($CHCl_3$, *c* 1.65). Purification by flash chromatography on silica gel eluting with (4:1) cyclohexane-ethyl acetate gave a product with a rotation of $[\alpha]_D$ −95.5° ($CHCl_3$, *c* 0.78), (lit.[3,4] $[\alpha]_D$ −105°). Checkers report the following data for **5**: $[\alpha]_D^{23}$ −93.3° ($CHCl_3$, *c* 1.10); ^{1}H NMR (400 MHz, C_6D_6, 70°C) δ: 1.34 (s, 9 H), 1.40 (br s, 3 H), 1.58 (br s, 3 H), 3.57 (d, 1 H, J = 7.6), 3.67 (d, 1 H, J = 7.6), 3.91 (m, 1 H), 9.33 (br s, 1 H) ; ^{13}C NMR (100 MHz, C_6D_6, 70°C) δ: 24.1, 26.0, 28.3, 63.7, 65.1, 80.6, 95.0, 151.8, 198.0 ; IR (neat) cm^{-1}: 1739, 1710 . Anal. Calcd for $C_{11}H_{19}NO_4$: C, 57.63; H, 8.35; N, 6.11. Found: C, 57.59; H, 8.27; N, 5.91.
22. Enantiomeric purity was determined to be 96-98% by ^{1}H NMR analysis of the Mosher esters[5] of the alcohols **4** and ent-**4** obtained by reduction of the aldehydes **5** and ent-**5**. To an ice-cold solution of aldehyde **5** (0.10 g, 0.44 mmol) in 5 mL of methanol was added solid sodium borohydride (33 mg, 0.88 mmol). After the mixture was stirred for 30 min at this temperature, the TLC in (7:3) cyclohexane-ethyl acetate showed the clean formation of the alcohol **4**. The mixture was treated with 0.05 mL of acetone and concentrated to dryness under reduced pressure. The residue was partitioned between water (10 mL) and ethyl acetate (10 mL) and the phases were separated. The aqueous phase was extracted with three 10-mL portions of ethyl acetate . The combined organic phases were dried with anhydrous sodium sulfate and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel eluting with (7:3) cyclohexane-ethyl acetate to give 71 mg (70% yield) of pure alcohol **4** as a colorless oil: $[\alpha]_D$ −26.4° ($CHCl_3$, *c* 0.58). To a solution of the alcohol (50 mg, 0.22 mmol), N,N'-dicyclohexylcarbodiimide (54 mg, 0.26 mmol) and 4-dimethylaminopyridine (3.0 mg, 0.025 mmol) in dry methylene chloride (0.5 mL) was added a solution of (R)-(+)-α-methoxy-α-(trifluoromethyl) phenylacetic acid (61 mg, 0.26 mmol, Aldrich Chemical Company, Inc.) in 0.26 mL of dry methylene chloride . The mixture was stirred overnight (14 hr) at room temperature, filtered to remove N,N'-dicyclohexylurea , and partitioned between ethyl acetate (3 × 5 mL) and water (5 mL). The combined organic phases were washed with 5-mL each of 1 M hydrochloric acid , water, and saturated aqueous sodium bicarbonate solution, then dried with anhydrous sodium sulfate and concentrated under reduced pressure. The residue was purified by flash chromatography over silica gel, eluting with (9:1) cyclohexane-ethyl acetate, to give 83 mg (84% yield) of product with the following properties: $[\alpha]_D$ +11.1° ($CHCl_3$, *c* 0.7); ^{1}H NMR (300 MHz, DMSO-d_6, 80°C) δ: 1.42 (s, 6 H), 1.44 (s, 9 H), 3.48 (s, 3 H), 3.69 (dd, 1 H, J = 2.5, 9.4), 3.96 (dd, 1 H, J = 6.0, 9.4), 4.01-4.11 (m, 1 H), 4.28 (dd, 1 H, J = 7.5, 10.5), 4.48 (dd, 1 H, J = 3.3, 10.5), 7.49 (s, 5 H) . The same procedure was performed with ent-**5**. The resulting ester showed the following properties: $[\alpha]_D$ +53.6° ($CHCl_3$, *c* 0.68); ^{1}H NMR (300 MHz, DMSO-d_6, 80°C) δ: 1.37 (s, 3 H), 1.41 (s, 3 H), 1.43 (s, 9 H), 3.50 (s, 3 H), 3.73 (dd, 1 H, J = 2.0, 9.4), 3.98 (dd, 1 H, J = 6.5, 9.4), 4.04-4.14 (m, 1 H), 4.28 (dd, 1 H, J = 7.3, 10.5), 4.46 (dd, 1 H, J = 3.1, 10.5), 7.49 (s, 5 H).

Waste Disposal Information

All toxic materials were disposed of in accordance with "Prudent Practices in the Laboratory"; National Academy Press; Washington, DC, 1995.

3. Discussion

Since the first appearance in the literature,[6] [7] the ingeniously protected serine-derived aldehyde **5** (Garner aldehyde) has attracted considerable attention as a model chiral α-amino carbonyl compound

for stereochemical studies,[8] [9] [10] [11] [12] [13] [14] and a precursor to interesting biologically active compounds such as amino sugars,[15] [16] aza sugars,[17] sphingosines,[18] [19] [20] [21] [22] [23] [24] [25] and unusual amino acids.[26] [27] [28] [29] [30] [31] [32] Compound **5** was designed[6,7] to meet some essential requirements for wide application in synthesis. These include: (1) easy and large scale preparation, (2) configurational and chemical stability, (3) high stereoselectivity during addition reactions, (4) easy and selective removal of O- and N-protective groups. Almost all these features occur and greatly increased the numerous synthetic applications of aldehyde **5** over the years. Nevertheless the issue regarding feature (1) is worth reconsideration since it is crucial to the exploitation of the advantages associated with features (2)-(4). The aim of this work is to provide an improved preparation of **5**, partly along the lines of the previous procedures reported by Garner[3,4] and McKillop[2] and their co-workers, partly by a new reaction sequence described by Roush and Hunt,[16] and by the submitters.[33]

The original Garner preparation[3,4] of **5** involves the conversion of serine into the protected methyl ester **3** and controlled reduction of the latter by DIBAL. The reaction sequence employed for the preparation of **3** involves the protection of the amino acid as N-Boc derivative using di-tert-butyl dicarbonate, esterification with methyl iodide or diazomethane , and acetonization with 2,2-dimethoxypropane under acid catalysis. The N-Boc methyl serinate and the ester **3** require purification by vacuum distillation or chromatography. In a modification to this procedure reported by McKillop,[2] the esterification reaction of serine is carried out first by methanol/acetyl chloride. The resulting ester is then converted into the N-Boc derivative **2** with di-tert-butyl dicarbonate and the latter transformed into **3** by acetonization. This procedure avoids the use of methyl iodide or diazomethane and the toxic solvent benzene and gives ester **3** pure enough for the reduction by DIBAL according to the Garner procedure above. Roush[16] and the submitters[33] have observed that the DIBAL reduction of **3** leads to a mixture of the aldehyde **5**, primary alcohol **4**, and unreacted methyl ester **3** that were difficult to separate. Therefore it proved more convenient to obtain aldehyde **5** by a two-stage reduction-oxidation sequence. Thus, Roush[16] reported the reduction of **3** to the protected serinol **4** by the use of lithium aluminum hydride and Swern oxidation of the latter to **5** with DMSO/$(COCl)_2$ in the presence of triethylamine. While the chemical yield of **5** was quite good (85%) the enantiomeric purity was determined to be 86-87%, much lower than that reported by the Garner method (93-95%).

In our procedure methyl ester **3** is obtained by the McKillop method.[2] Conditions and yields of steps A and B are essentially identical to those reported by McKillop. The reduction of crude **3** with lithium aluminum hydride (step C) to the alcohol **4** was essentially quantitative. Also this isolated compound did not require any purification for use in the next oxidation step (D). This was carried out by the Swern oxidation method[34] using DMSO and $(COCl)_2$ in the presence of a base. This crucial operation where Roush obtained considerable racemization of the resulting amino aldehyde **5**, was carried out in the presence of diisopropylethylamine [35] [36] (Hünig's base). This simple yet important modification provided **5** in good yield (79-85% from **1**) and enantiomeric purity (96-98%) comparable to that reported by Garner.

This preparation is referenced from:

- Org. Syn. Coll. Vol. 10, 140

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Appendix
Chemical Abstracts Nomenclature (Collective Index Number); (Registry Number)

N-[(1,1-Dimethylethoxy)carbonyl]-L-serine methyl ester:
L-Serine, N-[(1,1-dimethylethoxy)carbonyl]-, methyl ester (9); (2766-43-0)

Acetyl chloride (8,9); (75-36-5)

L-Serine (8,9); (56-45-1)

Di-tert-butyl dicarbonate:
Formic acid, oxydi-, di-tert-butyl ester (8);
Dicarbonic acid, bis(1,1-dimethylethyl) ester (9); (24424-99-5)

Triethylamine (8);
Ethanamine, N,N-diethyl- (9); (121-44-8)

3-(1,1-Dimethylethyl) 4-methyl (S)-2,2-dimethyl-3,4-oxazolidinedicarboxylate:
3,4-Oxazolidinedicarboxylic acid, 2,2-dimethyl-, 3-(1,1-dimethylethyl) 4-methyl ester, (S)- (12); (108149-60-6)

2,2-Dimethoxypropane:
Acetone, dimethyl acetal (8);
Propane, 2,2-dimethoxy- (9); (77-76-9)

Boron trifluoride etherate:
Ethyl ether, compd. with boron fluoride (1:1) (8);
Ethane, 1,1'-oxybis-, compd. with trifluoroborane (1:1) (9); (109-63-7)

N-[(1,1-Dimethylethoxy)carbonyl]-N,O-isopropylidene-L-serinol:
3-Oxazolidinecarboxylic acid, 4-(hydroxymethyl)-2,2-dimethyl-, 1,1-dimethylethyl ester (R)- (12);
(108149-63-9)

Lithium aluminum hydride:
Aluminate (1−), tetrahydro-, lithium (8);
Aluminate (1−), tetrahydro-, lithium (I-4)- (9); (16853-85-3)

1,1-Dimethylethyl (S)-4-formyl-2,2-dimethyl-3-oxazolidinecarboxylate:
3-Oxazolidinecarboxylic acid, 4-formyl-2,2-dimethyl-, 1,1-dimethylethyl ester, (S)- (11); (102308-32-7)

Dimethyl sulfoxide:
Methyl sulfoxide (8);
Methane, sulfinybis- (9); (67-68-5)

Oxalyl chloride: HIGHLY TOXIC (8);
Ethanedioyl dichloride (9); (79-37-8)

N,N-Diisopropylamine:
Triethylamine, 1,1'-dimethyl- (8);
2-Propanamine, N-ethyl-N-(1-methylethyl)- (9); (7087-68-5)

Sodium borohydride:
Borate (1−), tetrahydro-, sodium (8,9); (16940-66-2)

Dicyclohexylcarbodiimide: HIGHLY TOXIC:
Carbodiimide, dicyclohexyl- (8);
Cyclohexanamine, N,N'-methanetetraylbis- (9); (538-75-0)

4-Dimethylaminopyridine: HIGHLY TOXIC:
Pyridine, 4-(dimethylamino)- (8);
4-Pyridinamine, N,N-dimethyl- (9); (1122-58-3)

(R)-(+)-α-Methoxy-α-(trifluoromethyl)phenylacetic acid:
Hydratropic acid, β,β,β-trifluoro-α-methoxy-, (+)- (9); (20445-31-2)