SYNTHESSES OF 2-VINYL-2,3-DIHYDROPYRROLES AND 3-METHYLENE-1,2,3,4-TETRAHYDROPYRIDINES BY PALLADIUM-CATALYZED CYCLIZATION OF N-TOSYL IMINES WITH ALLYLIC DIESTERS

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Abstract – A palladium-catalyzed cyclization of N-tosyl imines with allylic diesters is described. The reactions of N-tosyl imines with 2-buten-1,4-diol dicarbonate and 2-methylene-1,3-propanediol diacetate afforded 2-vinyl-2,3-dihydropyrroles and 3-methylene-1,2,3,4-tetrahydropyridines, respectively.

INRODUCTION

Substituted dihydropyrroles and tetrahydropyridines are an important class of heteroaromatic compounds, and these are components as a structural fragment of biologically active natural products and pharmaceutical agents. From this reason, constructive effort has been devoted toward developing a methodology for the syntheses of substituted dihydropyrroles and tetrahydropyridines.

Palladium-catalyzed reactions of allylic diesters with bis-nucleophiles have received considerable attention and have been extensively studied. In these reactions, a substrate having two nucleophilic moieties within the molecule successively reacted with allylic diesters to afford the cyclized product. A variety of cyclic compounds can be synthesized in one-step by the choice of adequately designed nucleophilic molecules. For example, we have recently reported syntheses of functionalized dihydropyrroles and tetrahydropyridines by palladium-catalyzed cyclizations of β-enaminocarbonyl compounds with allylic diacetates (Scheme 1). In these reactions, β-enaminocarbonyl compounds react

† This paper is dedicated to Professor Dr. Masakatsu Shibasaki on the occasion of his 70th birthday.
with 1,4-diacyloxy-2-butene and 2-methylene-1,3-propanediol diacetate to afford substituted dihydropyrroles and tetrahydropyridines via successive double allylic substitutions, respectively. During the course of our planning for further investigation of this cyclization, we took notice of the nucleophilic activity of N-tosyl imines 1, which does not have electron-withdrawing carbonyl moiety. Herein, we describe a palladium-catalyzed cyclization of N-tosyl imines 1 with allylic diesters 2 and 4, in which the substituted dihydropyrroles 3 and tetrahydropyridines 5 were produced in one-step, respectively.

**Previous Work**

![Previous Work Scheme](image)

**This Work**

![This Work Scheme](image)

**Scheme 1**

**RESULTS AND DISCUSSION**

The examinations were started using phenyl-substituted N-tosyl imine 1a and (Z)-1,4-diacetoxy-2-butene (2a) (Table 1). When 1a and 2a were treated with 10 mol% Pd(OAc)$_2$, 20 mol% (±)-BINAP and 4 equiv K$_2$CO$_3$ in dioxane at 120 °C according to our previous condition,$^{2c}$ the expected 2-vinyl-2,3-dihydropyrrole 3a was produced in 63% yield (entry 1). The reactions in the presence of various base such as K$_3$PO$_4$, Cs$_2$CO$_3$, NaOH and iPr$_2$NEt resulted in the production of 3a in low yields, respectively (entries 2–5).$^8$ Experimenting using allylic dicarbonates 2b–2d in the absence of base
revealed that 3a was obtained in 62% yield in the case of benzyl carbonate 2d (entry 8). After attempts under various reaction temperature (entries 9 and 10), we found that the yield was increased to 70% when the reaction was carried out at 80 °C (entry 9).

Table 1. Initial attempts using 1a with 2a–2d

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>Base</th>
<th>Temp (°C)</th>
<th>Yield (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Ac (2a)</td>
<td>K$_2$CO$_3$</td>
<td>120</td>
<td>63</td>
</tr>
<tr>
<td>2</td>
<td>Ac (2a)</td>
<td>K$_3$PO$_4$</td>
<td>120</td>
<td>58</td>
</tr>
<tr>
<td>3</td>
<td>Ac (2a)</td>
<td>Cs$_2$CO$_3$</td>
<td>120</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>Ac (2a)</td>
<td>NaOH</td>
<td>120</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>Ac (2a)</td>
<td>$^i$Pr$_2$NEt</td>
<td>120</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>CO$_2$Me (2b)</td>
<td>–</td>
<td>120</td>
<td>57</td>
</tr>
<tr>
<td>7</td>
<td>CO$_2$Bu (2c)</td>
<td>–</td>
<td>120</td>
<td>41</td>
</tr>
<tr>
<td>8</td>
<td>CO$_2$Bn (2d)</td>
<td>–</td>
<td>120</td>
<td>62</td>
</tr>
<tr>
<td>9</td>
<td>CO$_2$Bn (2d)</td>
<td>–</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>CO$_2$Bn (2d)</td>
<td>–</td>
<td>50</td>
<td>49</td>
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</tbody>
</table>

Having identified a useful set of reaction conditions, we carried out a study using various aryl-substituted N-tosyl imines 1b–1f with 2d (Table 2). When a substrate 1b having a tolyl group was exposed to the optimal conditions, the dihydropyrrole 3b was obtained in 60% yield (entry 1). Methoxy- and fluoro-substituted substrates 1c–1e reacted without problems to afford the corresponding products 3c–3e in moderate yields, respectively (entries 2–4). The reaction of 1f which contains naphthyl group also proceeded to give the cyclized product 3f in 66% yield (entry 5).

We next conducted the reactions using 2-methylene-1,3-propanediol diacetate (4). When N-tosyl imine 1a and 4 were subjected to the reaction with 10 mol% Pd(OAc)$_2$, 20 mol% (±)-BINAP and 4 equiv K$_2$CO$_3$ in dioxane at 120 °C, the reaction successfully proceeded to produce the 3-methylene-1,2,3,4-tetrahydropyridine 5a in 94% yield (Scheme 2).
Table 2. Reactions using various aryl-substituted N-tosyl imines 1b–1f with 2d

<table>
<thead>
<tr>
<th>Entry</th>
<th>Substrate 1</th>
<th>Product 3</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td><img src="image2.png" alt="Image" /></td>
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<td>2</td>
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<td>56</td>
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<td>46</td>
</tr>
<tr>
<td>4</td>
<td><img src="image7.png" alt="Image" /></td>
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<tr>
<td>5</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td>66</td>
</tr>
</tbody>
</table>

*Reactions were carried out with 2c in the presence of 10 mol% Pd(OAc)$_2$, 20 mol% (±)-BINAP in dioxane at 80 °C.

![Scheme 2](image11.png)

Table 3 summarized the examinations using N-tosyl imines 1b–1f. The reactions of allylic diacetate 4 with tolyl-substituted N-tosyl imines 1b afforded the tetrahydropyridine 5b in 93% yield (entry 1). Similarly, substrates 1c–1f having various aryl group also reacted to give the corresponding products 5c–5f in good yields, respectively (entries 2–5).
A plausible mechanism for the production of dihydropyrrole 3 and tetrahydropyridine 5 are shown in Scheme 3. By the reaction with palladium, 2-butene-1,4-diol dicarbonate 2d is transformed to the π-allylpalladium complex 6, which causes the nucleophilic attack of the N-tosyl imine anion to afford the substituted allylic carbonate 7. The compound 7 is further subjected to the intramolecular nucleophilic attack of the tosyl amide anion via the formation of π-allylpalladium intermediate 8 to produce the 2,3-dihydropyrrole 3. 2-Methylene-1,3-propanediol diacetate 4 is also converted to the corresponding π-allylpalladium complex 9, which is subjected to the nucleophilic attack of the N-tosyl imine anion to afford allylic acetate 10. Then intramolecular nucleophilic cyclization of 10 occurs via the π-allylpalladium intermediate 11 to produce the tetrahydropyridine 5. In these reactions, it is interesting
that N-tosyl imines which does not have electron-withdrawing carbonyl group act as a bis-nucleophile in mild reaction conditions.

\[
\begin{align*}
\text{OCO}_2\text{Bn} & \quad \overset{\text{Pd}}{\longrightarrow} \quad \overset{\text{Pd}^+}{\text{OCO}_2\text{Bn}} \quad \overset{\text{N-Ts}}{\underset{\text{Ar}}{\text{N}} \text{Ts}} \quad \overset{\text{Pd}^+}{\underset{\text{base}}{\text{Ar}} \text{Ts}} \\
\text{2d} & \quad \overset{\text{6}}{\longrightarrow} \quad \overset{\text{7}}{\longrightarrow} \quad \overset{\text{8}}{\longrightarrow} \quad \overset{\text{3}}{\longrightarrow} \\
\text{OCO}_2\text{Bn} & \quad \overset{\text{Pd}}{\longrightarrow} \quad \overset{\text{Pd}^+}{\text{OCO}_2\text{Bn}} \quad \overset{\text{N-Ts}}{\underset{\text{Ar}}{\text{N}} \text{Ts}} \quad \overset{\text{Pd}^+}{\underset{\text{base}}{\text{Ar}} \text{Ts}} \\
4 & \quad \overset{\text{9}}{\longrightarrow} \quad \overset{\text{10}}{\longrightarrow} \quad \overset{\text{11}}{\longrightarrow} \quad \overset{\text{5}}{\longrightarrow}
\end{align*}
\]

\textbf{Scheme 3}

\textbf{CONCLUSIONS}

In conclusion, the studies described above have resulted in the synthesis of functionalized dihydropyrroles and tetrahydropyridines by the palladium-catalyzed cyclization of N-tosyl imines with allylic diesters. In this reaction, N-tosyl imines which does not have electron-withdrawing carbonyl moiety act as bis-nucleophile in mild reaction conditions. Since many biologically active molecules containing a pyrrolidine and piperidine component have been reported, our methodology could provide a new protocol for the syntheses of these compounds.

\textbf{EXPERIMENTAL}

All reactions were carried out under a positive atmosphere of argon in dried glassware unless otherwise indicated. Materials were obtained from commercial suppliers and used without further purification except when otherwise noted. Solvents were dried and distilled according to the standard protocols. N-tosyl imines 1 and allylic diesters 2 and 4 were prepared according to the procedures described in the literature.\textsuperscript{9,10,11}

\textbf{General Procedure for the Synthesis of Dihydropyrrole}

**Synthesis of 3a (entry 9 in Table 1):** To a stirred solution of N-tosyl imine 1a (20.0 mg, 73.2 µmol) in dioxane (0.7 mL) were added allylic dicarbonate 2d (26.1 mg, 73.2 µmol), Pd(OAc)\textsubscript{2} (1.6 mg, 7.3 µmol), and (±)-BINAP (9.1 mg, 14.6 µmol) at rt, and stirring was continued for 30 min at the same temperature.
under argon atmosphere. The reaction mixture was then allowed to heat to 80 °C, and further stirring was continued for 20 min. After filtration of the reaction mixture using small amount of silica gel followed by concentration, the residue was chromatographed on silica gel with AcOEt–hexane (1:8 v/v) as eluent to give 3a (16.7 mg, 51.2 μmol, 70%) as pale yellow needles.

5-Phenyl-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3a)

Yield 70%; pale yellow needles (AcOEt/hexane, mp 90.4–91.3 °C); IR (neat) 1352, 1167, 755, 666 cm⁻¹; ¹HNMR (400 MHz, CDCl₃) δ 2.00–2.05 (1H, m), 2.11–2.17 (1H, m), 2.43 (3H, s), 4.78–4.81 (1H, m), 5.19 (1H, d, J = 10.4 Hz), 5.39 (1H, dd, J = 2.0 and 3.6 Hz), 5.54 (1H, d, J = 16.8 Hz), 5.88 (1H, ddd, J = 4.8, 10.4 and 16.8 Hz), 7.26–7.29 (2H, m), 7.34–7.38 (3H, m), 7.57–7.59 (4H, m); ¹³C-NMR (100 MHz, CDCl₃) δ 21.6 (CH₃), 35.3 (CH₂), 64.1 (CH), 114.9 (CH₂), 116.0 (CH), 127.5 (CH), 127.8 (CH), 127.9 (CH), 128.6 (CH), 129.4 (CH), 133.3 (Cq), 134.4 (Cq), 137.5 (CH), 143.7 (Cq), 144.1 (Cq); HRMS (ESI) m/z calcd for C₁₉H₁₅NaO₃S [M+Na]⁺ 348.1034, found 348.1032.

5-(4-Methylphenyl)-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3b)

Yield 60%; pale yellow needles (AcOEt/hexane, mp 93.5–96.0 °C); IR (neat) 1352, 1167, 1091, 820 cm⁻¹; ¹HNMR (400 MHz, CDCl₃) δ 1.98–2.02 (1H, m), 2.07–2.14 (1H, m), 2.37 (3H, s), 2.43 (3H, s), 4.76–4.79 (1H, m), 5.18 (1H, d, J = 10.0 Hz), 5.33 (1H, dd, J = 2.0 and 3.6 Hz), 5.53 (1H, d, J = 16.8 Hz), 5.88 (1H, ddd, J = 5.2, 10.0 and 16.8 Hz), 7.17 (2H, d, J = 8.4 Hz), 7.27 (2H, d, J = 8.4 Hz), 7.48 (2H, d, J = 8.4 Hz), 7.58 (2H, d, J = 8.4 Hz); ¹³C-NMR (100 MHz, CDCl₃) δ 21.3 (CH₃), 21.6 (CH₃), 34.2 (CH₂), 64.1 (CH), 114.9 (CH₂), 115.1 (CH), 127.5 (CH), 127.8 (CH), 128.6 (CH), 129.3 (CH), 130.4 (Cq), 134.5 (Cq), 137.6 (CH), 138.6 (Cq), 143.6 (Cq), 144.1 (Cq); HRMS (ESI) m/z calcd for C₂₀H₂₁NaO₃S [M+Na]⁺ 362.1191, found 362.1189.

5-(4-Methoxyphenyl)-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3c)

Yield 56%; pale red needles (AcOEt/hexane, mp 112.5–114.2 °C); IR (neat) 1508, 1457, 1250, 1166 cm⁻¹; ¹HNMR (400 MHz, CDCl₃) δ 1.97–2.03 (1H, m), 2.08-2.14 (1H, m), 2.43 (3H, s), 3.82 (3H, s), 4.75–4.80 (1H, m), 5.18 (1H, d, J = 10.4 Hz), 5.27 (1H, dd, J = 2.0 and 3.4 Hz), 5.52 (1H, d, J = 17.2 Hz), 5.88 (1H, ddd, J = 5.6, 10.4 and 17.2 Hz), 6.90 (2H, d, J = 8.8 Hz), 7.27 (2H, d, J = 8.8 Hz), 7.51 (2H, d, J = 8.8 Hz), 7.57 (2H, d, J = 8.8 Hz); ¹³C-NMR (100 MHz, CDCl₃) δ 21.6 (CH₃), 34.1 (CH₂), 55.3 (CH₃), 64.1 (CH), 113.3 (CH), 114.2 (CH₂), 114.9 (CH), 125.8 (Cq), 127.8 (CH), 128.9 (CH), 129.3 (CH) 134.5 (Cq), 137.6 (CH), 143.6 (Cq), 143.7 (Cq), 159.9 (Cq); HRMS (ESI) m/z calcd for C₂₀H₂₂NO₃S [M+H]⁺ 356.1320, found 356.1318.

5-(3-Methoxyphenyl)-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3d)

Yield 46%; colorless needles (AcOEt/hexane, mp 95.1–98.2 °C); IR (neat) 1353, 1166, 1041, 668 cm⁻¹; ¹HNMR (400 MHz, CDCl₃) δ 1.99–2.05 (1H, m), 2.10–2.17 (1H, m), 2.43 (3H, s), 3.84 (3H, s)
4.77–4.81 (1H, m), 5.19 (1H, d, J = 10.4 Hz), 5.40 (1H, dd, J = 2.0 and 4.0 Hz), 5.52 (1H, d, J = 17.2 Hz), 5.88 (1H, ddd, J = 5.2, 10.4 and 17.2 Hz), 6.88–6.90 (1H, m), 7.11–7.12 (1H, m), 7.16–7.18 (1H, m), 7.25–7.30 (3H, m), 7.60 (2H, d, J = 7.6 Hz); $^{13}$C-NMR (100 MHz, CDCl$_3$) δ 21.6 (CH$_3$), 34.3 (CH$_2$), 55.3 (CH$_3$), 64.1 (CH), 113.3 (CH), 114.2 (CH), 115.0 (CH$_2$), 116.4 (CH), 120.1 (CH), 127.8 (CH), 128.9 (CH), 129.3 (CH), 129.6 (Cq), 134.6 (Cq), 137.5 (CH), 143.7 (Cq), 143.9 (Cq), 159.1 (Cq); HRMS (ESI) m/z calcd for C$_{20}$H$_{21}$NNa$_3$O$_3$ [M+Na]$^+$ 378.1140, found 378.1136.

5-(4-Fluorophenyl)-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3e)

Yield 54%; yellow needles (AcOEt/hexane, mp 120.5–123.7 °C); IR (neat) 1507, 1353, 1222, 1167 cm$^{-1}$; $^{1}$H-NMR (400 MHz, CDCl$_3$) δ 2.00–2.06 (1H, m), 2.11–2.18 (1H, m), 2.44 (3H, s), 4.77–4.81 (1H, m), 5.20 (1H, d, J = 10.4 Hz), 5.34 (1H, dd, J = 2.4 and 3.6 Hz), 5.51 (1H, d, J = 17.2 Hz), 5.88 (1H, ddd, J = 5.2, 10.4 and 17.2 Hz), 7.05 (2H, t, J = 8.8 Hz), 7.28 (2H, d, J = 8.4 Hz), 7.54 (2H, t, J = 8.8 Hz), 7.56 (2H, d, J = 8.4 Hz); $^{13}$C-NMR (100 MHz, CDCl$_3$) δ 21.6 (CH$_3$), 34.3 (CH$_2$), 64.1 (CH), 114.9 (CH, d, J = 21.5 Hz), 115.2 (CH$_2$), 115.8 (CH), 117.8 (CH), 129.3 (CH, d, J = 7.4 Hz), 129.4 (Cq), 129.4 (CH), 134.4 (Cq), 137.5 (CH), 143.0 (Cq), 143.8 (Cq), 162.9 (Cq, d, J = 247.0 Hz); HRMS (ESI) m/z calcd for C$_{19}$H$_{19}$FNO$_3$S [M+H]$^+$ 344.1121, found 344.1118.

5-(Naphthalen-2-yl)-1-tosyl-2-vinyl-2,3-dihydro-1H-pyrrole (3f)

Yield 66%; pale orange needles (AcOEt/hexane, mp 135.3–137.0 °C); IR (neat) 1353, 1167, 772, 667 cm$^{-1}$; $^{1}$H-NMR (400 MHz, CDCl$_3$) δ 2.05–2.11 (1H, m), 2.17–2.24 (1H, m), 2.43 (3H, s), 4.83–4.87 (1H, m), 5.23 (1H, d, J = 10.4 Hz), 5.52 (1H, dd, J = 2.0 and 3.6 Hz), 5.58 (1H, d, J = 16.8 Hz), 5.93 (1H, ddd, J = 5.6, 10.4 and 16.8 Hz), 7.27 (2H, d, J = 8.4 Hz), 7.46–7.51 (2H, m), 7.60 (2H, d, J = 8.4 Hz), 7.70–7.72 (1H, m), 7.81–7.87 (3H, m), 8.00 (1H, s); $^{13}$C-NMR (100 MHz, CDCl$_3$) δ 21.6 (CH$_3$), 34.4 (CH$_2$), 64.2 (CH), 115.1 (CH$_2$), 116.6 (CH), 125.6 (CH), 126.2 (CH), 126.3 (CH), 126.4 (CH), 127.4 (CH), 127.7 (CH), 127.8 (CH), 128.2 (CH), 129.4 (CH), 130.7 (Cq), 132.9 (Cq), 133.5 (Cq), 134.5 (Cq), 137.5 (CH), 143.8 (Cq), 144.1 (Cq); HRMS (ESI) m/z calcd for C$_{23}$H$_{21}$NNa$_2$O$_3$ [M+Na]$^+$ 398.1191, found 398.1189.

General Procedure for the Synthesis of Tetrahydropyridine

**Synthesis of 5a (Scheme 2):** To a stirred solution of N-tosyl imine 1a (27.3 mg, 100 μmol) in dioxane (1.0 mL) were added allylic diacetate 4 (34.4 mg, 200 μmol), Pd(OAc)$_2$ (2.2 mg, 10.0 μmol), (+)-BINAP (12.5 mg, 20.0 μmol), and K$_2$CO$_3$ (55.3 mg, 400 μmol) at rt, and stirring was continued for 30 min at the same temperature under argon atmosphere. The reaction mixture was then allowed to heat to 120 °C, and further stirring was continued for 20 min. After filtration of the reaction mixture using small amount of
silica gel followed by concentration, the residue was chromatographed on silica gel with AcOEt–hexane (1:6 v/v) as eluent to give tetrahydropyridine 5a (30.6 mg, 94.0 µmol, 94%) as pale yellow oil.

3-Methylene-6-phenyl-1-tosyl-1,2,3,4-tetrahydropyridine (5a)
Yield 94%; yellow needles (AcOEt/hexane, mp 83.7–85.0 °C); IR (neat) 1350, 1163, 763, 695 cm⁻¹; \(^1\)H-NMR (400 MHz, CDCl₃) δ 2.40 (3H, s), 2.57–2.85 (2H, m), 4.23 (2H, s), 4.66 (1H, s), 4.81 (1H, s), 5.68 (1H, t, J = 4.0 Hz), 7.19 (2H, d, J = 8.4 Hz), 7.31–7.37 (3H, m), 7.51–7.53 (4H, m); \(^1\)C-NMR (100 MHz, CDCl₃) δ 21.5 (CH₃), 29.9 (CH₂), 53.2 (CH₂), 112.1 (CH₂), 120.1 (CH), 126.6 (CH), 128.0 (CH), 128.1 (CH), 128.3 (CH), 128.9 (CH), 135.4 (Cq), 138.1 (Cq), 138.7 (Cq), 140.3 (Cq), 143.4 (Cq); HRMS (ESI) m/z calcd for C₁₀H₁₉NNaO₂S [M+Na]⁺ 348.1034, found 348.1033.

3-Methylene-6-(4-methylphenyl)-1-tosyl-1,2,3,4-tetrahydropyridine (5b)
Yield 93%; yellow needles (AcOEt/hexane, mp 108.5–111.8 °C); IR (neat) 1352, 1164, 813, 691 cm⁻¹; \(^1\)H-NMR (400 MHz, CDCl₃) δ 2.36 (3H, s), 2.39 (3H, s), 2.54 (2H, s), 4.22 (2H, s), 4.65 (1H, s), 4.80 (1H, s), 5.63 (1H, t, J = 4.0 Hz), 7.15 (2H, d, J = 8.0 Hz), 7.17 (2H, d, J = 8.0 Hz), 7.41 (2H, d, J = 8.0 Hz), 7.52 (2H, d, J = 8.0 Hz); \(^1\)C-NMR (100 MHz, CDCl₃) δ 21.2 (CH₃), 21.5 (CH₃), 29.9 (CH₂), 53.2 (CH₂), 111.9 (CH₂), 119.2 (CH), 126.5 (CH), 128.3 (CH), 128.7 (CH), 128.8 (CH), 135.4 (Cq), 135.9 (Cq), 137.9 (Cq), 138.3 (Cq), 140.3 (Cq), 143.3 (Cq); HRMS (ESI) m/z calcd for C₂₀H₂₁NNaO₂S [M+Na]⁺ 362.1191, found 362.1190.

6-(4-Methoxyphenyl)-3-methylene-1-tosyl-1,2,3,4-tetrahydropyridine (5c)
Yield 91%; orange needles (AcOEt/hexane, mp 51.3–54.9 °C); IR (neat) 1606, 1509, 1349, 1249, 1163 cm⁻¹; \(^1\)H-NMR (400 MHz, CDCl₃) δ 2.40 (3H, s), 2.54–2.55 (2H, m), 3.83 (3H, s), 4.22 (2H, s), 4.66 (1H, s), 4.82 (1H, s), 5.57 (1H, t, J = 4.2 Hz), 6.88 (2H, d, J = 8.8 Hz), 7.18 (2H, d, J = 8.0 Hz), 7.44 (2H, d, J = 8.8 Hz), 7.51 (2H, d, J = 8.0 Hz); \(^1\)C-NMR (100 MHz, CDCl₃) δ 21.5 (CH₃), 29.8 (CH₂), 53.3 (CH₂), 55.3 (CH₃), 111.9 (CH₂), 113.4 (CH), 118.4 (CH), 127.9 (CH), 128.3 (CH), 128.8 (CH), 131.3 (Cq), 135.4 (Cq), 138.4 (Cq), 139.9 (Cq), 143.3 (Cq), 159.6 (Cq); HRMS (ESI) m/z calcd for C₂₀H₂₁NNaO₂S [M+Na]⁺ 378.1140, found 378.1135.

6-(3-Methoxyphenyl)-3-methylene-1-tosyl-1,2,3,4-tetrahydropyridine (5d)
Yield 91%; colorless needles (AcOEt/hexane, mp 105.0–107.0 °C); IR (neat) 1352, 1163, 1040, 776 cm⁻¹; \(^1\)H-NMR (400 MHz, CDCl₃) δ 2.39 (3H, s), 2.56–2.57 (2H, m), 3.82 (3H, s), 4.22 (2H, s), 4.67 (1H, s), 4.82 (1H, s), 5.69 (1H, t, J = 4.0 Hz), 6.84–6.86 (1H, m), 7.03–7.04 (1H, m), 7.10–7.12 (1H, m), 7.18 (2H, d, J = 8.0 Hz), 7.23–7.27 (1H, m), 7.53 (2H, d, J = 8.0 Hz); \(^1\)C-NMR (100 MHz, CDCl₃) δ 21.5 (CH₃), 29.9 (CH₂), 53.2 (CH₂), 55.2 (CH₃), 112.0 (CH₂), 112.4 (CH), 113.6 (CH), 119.2 (CH), 120.3 (CH), 128.3 (CH), 128.9 (CH), 128.9 (CH), 135.5 (Cq), 136.3 (Cq), 138.2 (Cq), 140.0 (Cq), 143.4 (Cq), 159.3 (Cq); HRMS (ESI) m/z calcd for C₂₀H₂₁NNaO₂S [M+Na]⁺ 378.1140, found 378.1136.
6-(4-Fluorophenyl)-3-methylene-1-tosyl-1,2,3,4-tetrahydropyridine (5e)

Yield 87%; yellow needles (AcOEt/hexane, mp 109.5–111.5 °C); IR (neat) 1507, 1351, 1221, 1164 cm⁻¹; ¹H-NMR (400 MHz, CDCl₃) δ 2.40 (3H, s), 2.57–2.58 (2H, m), 4.22 (2H, s), 4.67 (1H, s), 4.82 (1H, s), 5.62 (1H, t, J = 4.2 Hz), 7.03 (2H, t, J = 8.8 Hz), 7.19 (2H, d, J = 8.4 Hz), 7.46–7.52 (4H, m); ¹³C-NMR (100 MHz, CDCl₃) δ 21.5 (CH₃), 29.9 (CH₂), 53.2 (CH₂), 112.2 (CH₂), 114.9 (CH, d, J = 21.5 Hz), 119.8 (CH), 128.3 (CH, d, J = 7.5 Hz), 128.3 (CH), 134.9 (Cq), 135.3 (Cq), 137.9 (Cq), 139.4 (Cq), 143.5 (Cq), 162.7 (Cq, d, J = 246.2 Hz); HRMS (ESI) m/z calcd for C₁₉H₁₈FNNaO₂S [M+Na]+ 366.0940, found 366.0941.

3-Methylene-6-(naphthalen-2-yl)-1-tosyl-1,2,3,4-tetrahydropyridine (5f)

Yield 92%; colorless needles (AcOEt/hexane, mp 139.3–142.1 °C); IR (neat) 1351, 1164, 771, 669 cm⁻¹; ¹H-NMR (400 MHz, CDCl₃) δ 2.39 (3H, s), 2.64–2.65 (2H, m), 4.30 (2H, s), 4.71 (1H, s), 4.86 (1H, s), 5.81 (1H, t, J = 4.0 Hz), 7.18 (2H, d, J = 8.4 Hz), 7.45–7.49 (2H, m), 7.54 (2H, d, J = 8.4 Hz), 7.66–7.68 (1H, m), 7.80–7.84 (3H, m), 7.92 (1H, s); ¹³C-NMR (100 MHz, CDCl₃) δ 21.5 (CH₃), 30.1 (CH₂), 53.2 (CH₂), 112.1 (CH₂), 120.7 (CH), 125.1 (CH), 125.3 (CH), 125.9 (CH), 126.0 (CH), 127.4 (CH), 127.7 (CH), 128.2 (CH), 128.3 (CH), 128.9 (CH), 133.2 (Cq), 133.3 (Cq), 135.6 (Cq), 136.2 (Cq), 138.2 (Cq), 140.4 (Cq), 143.4 (Cq); HRMS (ESI) m/z calcd for C₂₃H₂₁NNaO₂S [M+Na]+ 398.1191, found 398.1196.

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REFERENCES AND NOTES


8. In each case, the byproducts were not observed and the decomposition of the starting material was occurred except for the production of 3a.

