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Unexpected Ti^{III}/Mn-Promoted Pinacol Coupling of Ketones

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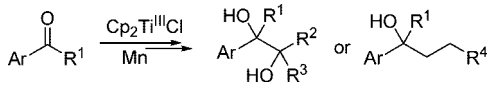
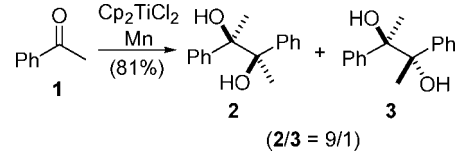


Titanocene(III) chemistry has emerged in the last decades as an indispensable tool in C−C bond-forming reactions. In this context, pinacol and related reactions allow the stereoselective synthesis of vicinal diols. In this work, we present new applications of these reactions using as starting materials aromatic ketones. Simple and smooth reaction conditions have been developed and have been applied for inter- and intramolecular processes. We also describe that although Cp_2TiCl is usually used as a monoelectronic reducing agent, it can be also used as an efficient Lewis acid.

During the last two decades, bis(cyclopentadienyl)titanium(III) chloride, Nugent's reagent (Cp_2TiCl), has become a formidable tool in organic synthesis,[1] facilitating unprecedented chemical transformations as useful as the homolytic ring-opening of epoxides,[2] the radical cascade cyclization of epoxypolyenes,[3] the Michael-type coupling between aldehydes and conjugated alkenals,[4] the H-atom transfer from water to free radicals,[5] alkenes and alkynes,[6] a divergent C−C bond-forming reaction with modulation by Ni or Pd,[7] or the metal-catalyzed Barbier-type cyclization and α-prenylation of carbonyl derivatives.[8] Moreover, several authors have shown how Nugent's reagent is capable of promoting pinacol couplings of conjugated aldehydes,[9] but in contrast, Barden and Schwartz reported that Nugent's reagent showed low reactivity toward pinacol coupling of aromatic ketones.[10]

SCHEME 1. Pinacol Coupling of 1 Promoted by Cp_2TiCl_2/Mn



Nevertheless, we have serendipitously found that treatment of acetophenone (**1**) with Nugent's reagent, generated in situ by stirring Cp_2TiCl_2 with an excess of Mn dust,[11] provided pinacol-coupling products **2** and **3** with good overall yield (81%) and considerable stereoselectivity (*dl*/*meso* ratio = 9/1) (Scheme 1).[12] The above result attracted our attention due not only to the potential synthetic value of this selective C−C bond-forming reaction but also to the apparent discrepancy with the Barden and Schwartz's observations.

To clarify this discrepancy, we prepared solid $(Cp_2TiCl)_2$ as described by these authors[10] and treated model ketone **1** with this dinuclear form of Nugent's reagent. In this manner, we obtained only 10% of a **2**/**3** mixture (*dl*/*meso* = 2/1) confirming the relatively low reactivity of the $(Cp_2TiCl)_2$ dimer. We subsequently treated **1** with $(Cp_2TiCl)_2$ and an excess of Mn dust. Under these conditions, similar to those employed in the reaction with Nugent's reagent generated in situ, we obtained products **2** and **3** with overall yield (72%) and stereoselectivity (*dl*/*meso* = 16/1) similar to those depicted in Scheme 1. Moreover, when we used the combination of $(Cp_2TiCl)_2$ and

(1) For pertinent reviews, see: (a) Gansäuer, A.; Bluhm, H. *Chem. Rev.* **2000**, *100*, 2771–2788. (b) Gansäuer, A.; Pierobon, M. In *Radicals in Organic Synthesis*; Renaud, P., Sibi, M. P., Eds.; Wiley-VCH: Weinheim, Germany, 2001; Vol. 2, pp 207−220. (c) Gansäuer, A.; Narayan, S. *Adv. Synth. Catal.* **2002**, *344*, 465–475. (d) Gansäuer, A.; Lauterbach, T.; Narayan, S. *Angew. Chem., Int. Ed.* **2003**, *42*, 5556–5573. (e) Cuerva, J. M.; Justicia, J.; Oller-López, J. L.; Oltra, J. E. *Top. Curr. Chem.* **2006**, *264*, 63–91.

(2) For pioneering reports on epoxide opening promoted by Nugent's reagent, see:(a) RajanBabu, T. V.; Nugent, W. A. *J. Am. Chem. Soc.* **1994**, *116*, 986–997, and references cited therein. (b) Gansäuer, A.; Bluhm, H.; Pierobon, M. *J. Am. Chem. Soc.* **1998**, *120*, 12849–12859. (c) Barrero, A. F.; Rosales, A.; Cuerva, J. M.; Oltra, J. E. *Org. Lett.* **2003**, *5*, 1935–1938.

(3) (a) Justicia, J.; Rosales, A.; Buñuel, E.; Oller-López, J. L.; Valdivia, M.; Haïdour, A.; Oltra, J. E.; Barrero, A. F.; Cárdenas, D. J; Cuerva, J. M. *Chem.—Eur. J.* **2004**, *10*, 1778–1788. (b) Justicia, J. E; Oltra, J. M; Cuerva, *J. Org. Chem.* **2004**, *69*, 5803–5806. (c) Justicia, J.; Oltra, J. E.; Cuerva, J. M. *J. Org. Chem.* **2005**, *70*, 8265–8272. (d) Justicia, J.; Oller-López, J. L.; Campaña, A. G.; Oltra, J. E.; Cuerva, J. M.; Buñuel, E.; Cárdenas, D. J. *J. Am. Chem. Soc.* **2005**, *127*, 14911–14921.

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(5) Cuerva, J. M.; Campaña, A. G.; Justicia, J.; Rosales, A.; Oller-López, J. L.; Robles, R.; Cárdenas, D.; Buñuel, E.; Oltra, J. E. *Angew. Chem., Int. Ed.* **2006**, *45*, 5522–5526.

(6) Campaña, A. G.; Estévez, R. E.; Fuentes, N.; Robles, R.; Cuerva, J. M.; Buñuel, E.; Cárdenas, D.; Oltra, J. E. *Org. Lett.* **2007**, *9*, 2195–2198.

(7) Campaña, A. G.; Bazdi, B.; Fuentes, N.; Robles, R.; Cuerva, J. M.; Oltra, J. E.; Porcel, S.; Echavarren, A. M. *Angew. Chem., Int. Ed.* **2008**, *47*, 7515–7519.

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(9) (a) Handa, Y.; Inanaga, J. *Tetrahedron Lett.* **1987**, *28*, 5717–5718. (b) Gansäuer, A. *Chem. Commun.* **1997**, 457–458. (c) Gansäuer, A.; Bauer, D. *J. Org. Chem.* **1998**, *63*, 2070–2071. (d) Gansäuer, A.; Bauer, D. *Eur. J. Org. Chem.* **1998**, 2673–2676. (e) Hirao, T.; Hatano, B.; Asahara, M.; Muguruma, Y.; Ogawa, A. *Tetrahedron Lett.* **1998**, *39*, 5247–5248. (f) Dunlap, M. S.; Nicholas, K. M. *J. Organomet. Chem.* **2001**, *630*, 125–131.

(10) Barden, M. C.; Schwartz, J. *J. Am. Chem. Soc.* **1996**, *118*, 5484–5485.

(11) Nugent's reagent generated in situ by stirring commercial Cp_2TiCl_2 with Zn or Mn dust in THF exists as an equilibrium mixture of the monomer Cp_2TiCl and the dinuclear species $(Cp_2TiCl)_2$; see: (a) Enemærke, R. J.; Larsen, J.; Skrydstrup, T.; Daasbjerg, K. *J. Am. Chem. Soc.* **2004**, *126*, 7853–7864. (b) Daasbjerg, K.; Svith, H.; Grimme, S.; Gerenkamp, M.; Mück-Lichtenfeld, C.; Gansäuer, A.; Barchuck, A.; Keller, F. *Angew. Chem., Int. Ed.* **2006**, *45*, 2041–2044. (c) Gansäuer, A.; Barchuk, A.; Keller, F.; Schmitt, M.; Grimme, S.; Gerenkamp, M.; Mück-Lichtenfeld, C.; Daasbjerg, K.; Svith, H. *J. Am. Chem. Soc.* **2007**, *129*, 1359–1371.

(12) Oller-López, J. L.; Campaña, A. G.; Cuerva, J. M.; Oltra, J. E. *Synthesis* **2005**, 2619–2622.

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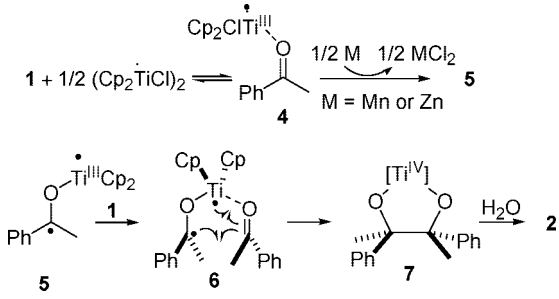
SCHEME 2. Proposed Mechanism for $(Cp_2TiCl)_2$/M-Mediated Coupling of 1



Zn dust, we obtained closely related results.[13] What is more, when we used a substoichiometric proportion of $(Cp_2TiCl)_2$ (0.3 equiv) and Mn or Zn dust, both good yields (74−82%) and stereoselectivities (*dl*/*meso* = 15/1) were retained. Finally, after control experiments with Mn or Zn, in the absence of titanium, pinacol coupling products were not detected and ketone **1** was recovered unchanged.[13] The high stereoselection obtained suggests that a bulky titanocene(III) complex is directly involved in the pinacol coupling process.[14,15] It is worth noting that there are few examples of pinacol couplings of acetophenone derivatives with high stereoselection.[16]

Although it has been described that $(Cp_2TiCl)_2$ promotes the pinacolization of aromatic and α,β-unsaturated aldehydes[9] via an inner-sphere electron transfer generating the corresponding titanoxy radicals, our experimental results suggest that in this case a smooth reducing agent such as $(Cp_2TiCl)_2$ (E^0 for Cp_2TiCl_2/Cp_2TiCl is −0.8 V vs Fc^+/Fc)[11a,17] is not acting as a simple single electron donor. Mn dust, a stronger reducing agent[18] present in the reaction media, was also unable to promote the pinacolization reaction of **1**. Nevertheless, it is known that metals with Lewis acid character are able to decrease the E^0 values in the electrochemical reduction of carbonyl compounds.[19] Moreover, it is known that mixtures of $Zn/ZnCl_2$ are able to pinacolize acetophenone in 50% aqueous THF at 70 °C, although without significant stereoselection.[20]

Based on these precedents, the experimental results can be easily rationalized if the mechanism depicted in Scheme 2 is accepted.[21] In this mechanism titanium plays a double role: (i) as a Lewis acid to coordinate with ketone **1**, facilitating the single-electron transfer from the reductive metal to the coordinated carbonyl group, and (ii) as a template responsible for the stereoselectivity observed. The Lewis acid character of titanocene(III) and the ability of titanium to exert template effects are well documented,[3d,8b,22] and in fact, a high *dl* stereoselection has been associated with metal-bridged intermediates such as **6**.[15] To the best of our knowledge, however, this is the first evidence reported to date suggesting that a titanocene(III) can facilitate an outer sphere electron transfer from an heterogeneous metal and a coordinated ketone.

Based on these encouraging results, we extended the stereoselective Ti(III)/M(0)-mediated homocoupling pinacol reaction to other aromatic and α,β-unsaturated ketones (Table 1, entries 1−4).[23]

As expected, we obtained the homocoupling pinacol products of different aromatic ketones (entries 1−3) and mesityl oxide (entry 4) in good to moderate yields maintaining the *dl* stereoselectivity. Although the effect of the substituents has not been studied in depth it does not seem to affect substantially the stereoselectivity.

Moreover, intermediate species **5** would have nucleophilic character, thus achieving the "umpolung" of the intrinsically electrophilic ketone like **1**, and can be used to carry out inter- and intramolecular cross-coupling reactions.

Therefore, we checked the ability of titanocene(III) to promote pinacol coupling between dissimilar ketones. Initially, we stirred acetophenone **1** with Cp_2TiCl (1.1 mmol) in THF/acetone during 1 h at room temperature. In this manner, we obtained the intermolecular cross-coupling product, 2,3-dihydroxy-2-methyl-3-phenylbutane **19** (entry 5), isolated by flash chromatography at an 83% yield. This result showed that in our reaction conditions ketone-derived ketyl radicals can attack an aliphatic ketone to give an unsymmetrical diol. An intramolecular version of this reaction would lead to cyclic vicinal diols. Bearing this idea in mind, we prepared substrates **12**−**14**,[13] and they were submitted to the standard reaction conditions. We obtained in moderate isolated yields (50−80%) the intramolecular cross-coupling products **20**−**22**, definitively confirming the first presumption of our hypothesis.

We only detected the *cis* isomer of cyclic diol **20**, but five- and six-membered rings were formed as mixtures of *cis*/*trans* diastereomers (**21**, 1:1; **22**, 3:1). The preference for *cis*-cyclohexanediol **22-cis** has synthetic value because it is complementary to the *trans*-selectivity observed in pinacol coupling of 1,6-dials catalyzed by bulky Cp_2TiPh.[24] Thus, titanocene chemistry becomes a versatile tool for the synthesis of 1,2-cyclohexanediols with reagent control on the stereochemistry. It should be noted that other synthetic methods recently reported can only provide *trans* isomers.[25]

The *cis*-stereoselectivity observed for Ti^{III}/M-promoted cyclizations of diketones **12** and **14** can be rationalized by the closed transition-state models **25** and **26**, respectively (Figure 1). In the intermediate **25**, the geometry of the cyclobutane ring imposes a *cis* configuration which leads to the *cis* diol **20**. In transition state **26-*cis***, only one of the bulky substituents (phenyl

(13) For more details, including experimental ones, see the Supporting Information.

(14) For a helpful discussion about the stereoselectivity in Ti^{III}-mediated pinacolizations, see: Enemærke, R. J.; Larsen, J.; Hjollund, G. H.; Skrydstrup, T.; Daasbjerg, K. *Organometallics* **2005**, *24*, 1252–1262.

(15) For a recent review of stereoselective pinacol coupling reactions, see: Chatterjee, A.; Joshi, N. N. *Tetrahedron* **2006**, *62*, 12137–12158.

(16) (a) Nishiyama, Y.; Shinomiya, E.; Kimura, S.; Itoh, K.; Sonoda, N. *Tetrahedron Lett.* **1998**, *39*, 3705–3708. (b) Ogawa, A.; Takeuchi, H.; Hirao, T. *Tetrahedron Lett.* **1999**, *40*, 7113–7114. (c) Arai, S.; Sudo, Y.; Nishida, A. *Chem. Pharm. Bull.* **2004**, *52*, 287–288. (d) Aspinall, H. C.; Greeve, N.; Valla, C. *Org. Lett.* **2005**, *7*, 1919–1922.

(17) Cyclic voltammograms of different titanocene(III) complexes determined in THF indicated potential values considerably less negative than that of SmI_2, one of the most commonly used single-electron-transfer reagents; see: Enemærke, R. J.; Daasbjerg, K.; Skrydstrup, T. *Chem. Commun.* **1999**, 343–344.

(18) The described E^0 value for Mn^{2+}/Mn is−1.18 vs hydrogen electrode: *Handbook of Chemistry and Physics*, 85th ed.; Lide, D. R., Ed.; CRC Press: Boca Raton, 2004; pp 8-25−8-26.

(19) (a) Douch, J.; Mousset, G. *Can. J. Chem.* **1987**, *65*, 549–556. (b) Fournier, F.; Fournier, M. *Can. J. Chem.* **1986**, *64*, 881–890.

(20) Tanaka, K.; Kishigami, S.; Toda, F. *J. Org. Chem.* **1990**, *55*, 2981–2983.

(21) Together with the nucleophilic-coupling mechanism depicted in Scheme 2, the conventional bimolecular radical−radical pinacol coupling mechanism[9] possibly coexists, but especially under the conditions with substoichiometric proportions of titanium, the former probably prevails.

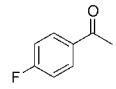
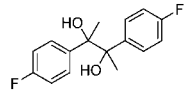
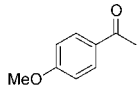
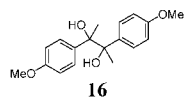
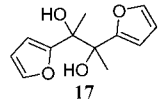
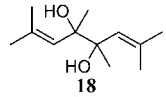
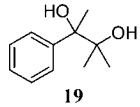
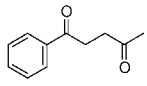
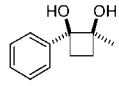
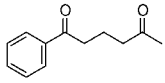
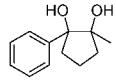
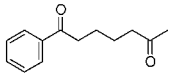
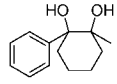
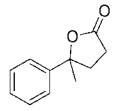
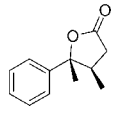
(22) Sato, F.; Iida, K.; Ijima, S.; Moriya, H.; Sato, M. *Chem. Commun.* **1981**, 1140–1141.

(23) Aliphatic ketones were inert under these reaction conditions.

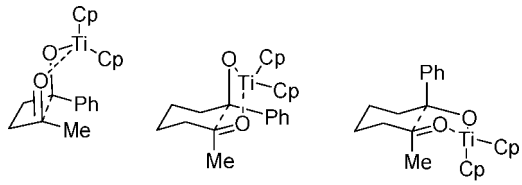
(24) Yamamoto, Y.; Hattori, R.; Miwa, T.; Nakagai, Y.-i.; Kubota, T.; Yamamoto, C.; Okamoto, Y.; Itoh, K *J. Org. Chem.* **2001**, *66*, 3865–3870.

(25) (a) Fujiwara, T.; Tsuruta, Y.; Arizono, K.; Takeda, T. *Synlett* **1997**, 962–964. (b) Balskus, E. P.; Méndez-Andino, J.; Arbit, R. M.; Paquette, L. A. *J. Org. Chem.* **2001**, *66*, 6695–6704.

TABLE 1. Cp_2TiCl/M Dust C−C Bond-Forming Reactions[a]

Entry	Ketone	Product	Yield (%) (*dl:meso*)
1	 **8**	 **15**	91 (85:15)
2	 **9**	 **16**	68 (95:5)
3	 **10**	 **17**	91 (7:3)
4	 **11**	 **18**	55 (65:35)
5[b]	 **1**	 **19**	83
6[c]	 **12**	 **20**	50
7[c]	 **13**	 **21**	80[d]
8	 **14**	 **22**	67[e]
9[f]	 **1**	 **23**	72
10[g]	 **1**	 **24**	80[h]

[a] Carbonyl compound (1 mmol), Cp_2TiCl_2 (1.1 mmol), Mn (8 mmol). [b] 100 equiv of acetone was added. [c] Zn was used instead of Mn. [d] 1:1 mixture of *cis*/*trans* stereoisomers. [e] 3:1 mixture of *cis*/*trans* stereoisomers. [f] 20 equiv of methyl acrylate was added. [g] 20 equiv of methyl crotonate was added. [h] 1:7 mixture of *cis*/*trans* stereoisomers.



25 **26-cis** **26-trans**

FIGURE 1. Closed transition-state models **25** and **26**.

or methyl) is in an axial position, thus minimizing the unfavorable 1,3-diaxial interactions. In the hypothetical intermediate **26-*trans***, however, both phenyl and methyl groups would be in an axial disposition, thus raising the activation energy and consequently lowering the reaction rate toward the *trans* isomer of **14**. The higher conformational flexibility of five-membered rings would allow similar energies for both *cis* and *trans* transition states, and thus, *cis* and *trans* isomers were formed in similar proportions.

TABLE 2. Cp_2TiCl/Mn Dust-Catalyzed Pinacol Reactions

entry	ketone	product (dl/meso)	yield (%)
1	**1**	**2** (9:1)	83
2	**8**	**15** (9:1)	75
3	**9**	**16** (9:1)	71
4	**10**	**17** (7:3)	60
5	**11**	**18** (7:3)	75

The ketyl radicals generated by this Ti/Mn dust mixture can be also used in another interesting C−C bond-forming reaction such as a Michael-type addition to α,β-unsaturated esters. These reactions have been extensively carried out using SmI_2 as promoter of the ketyl radical.[26] Nevertheless, SmI_2 has some drawbacks often associated with its chemoselectivity, its high molecular weight, and its price.[26] For this purpose, we use 20 equiv of methyl acrylate and methyl crotonate as trapping agents for the initially formed ketyl radicals leading to lactones **23** (Table 1, entry 9) and **24** (Table 1, entry 10), respectively, in acceptable yields. The 7:1 *trans*/*cis* stereochemistry obtained for lactone **24** is almost correlated with the complete *E* stereochemistry of starting methyl crotonate, showing that minimal stereochemical information is lost during the addition reaction.

More interestingly, the pinacol coupling reaction of acetophenone and related ketones can be carried out using only 0.2 mmol of Cp_2TiCl and 3.0 mmol of Mn dust with the aid of a titanocene-regenerating agent (Table 2). In this case, the mixture of trimethylsilyl chloride (1.5 mmol) and 2,4,6-collidine (3.0 mmol) developed in our laboratory was used,[1c,27] giving, for example, the corresponding coupling products of acetophenone, **2** and **3**, in similar yield (83%) and stereoselectivity (9:1 *dl*/*meso*) than in the stoichiometric conditions. Control experiments showed that the mixture of Mn, trimethylsilyl chloride, and 2,4,6-collidine is unable to promote such pinacol couplings. We also found that the molar relationship between the titanocene and the trimethylsilyl chloride was critical in order to retain the stereoselectivity. Thus, for example, an increase in the amount of trimethylsilyl chloride (4 mmol) gave a 4:1 mixture of *dl*/*meso* stereoisomers (73%), probably due to an early rupture of the titanium−oxygen bond in species like **5** by the regenerating agent. It is also worth noting that to our knowledge it is the first time that acetophenone and related compounds have been pinacolized with high stereoselection using substoichiometric amount of a metallic catalyst.[28]

In summary, we have demonstrated that, in contrast to the low reactivity shown by $(Cp_2TiCl)_2$ alone, the combination of Nugent's reagent with a reductive metal (Mn or Zn) is capable of promoting the pinacol coupling of conjugated ketones with good yields and considerable stereoselectivity. This reaction has mechanistic subtleties such as the role played by the carbonyl-

(26) For a recent review, see: Kagan, H. B. *Tetrahedron* **2003**, *59*, 10351–10372.

(27) For other regenerating agents, see: (a) Reference 1b. (b) Gansäuer, A.; Bluhm, H.; Rinker, B.; Narayan, S.; Schick, M.; Lauterbach, T.; Pierobon, M. *Chem.—Eur. J.* **2003**, *9*, 531–542. (c) Gansäuer, A.; Lauterbach, T.; Narayan, S. *Angew. Chem., Int. Ed.* **2003**, *42*, 5556–5573. (d) Fuse, S.; Hanochi, M.; Doi, T.; Takahashi, T. *Tetrahedron Lett.* **2004**, *45*, 1961–1963.

(28) For a related titanium(III)-based system, see: Hirao, T.; Hatano, B.; Asahara, M.; Muguruma, Y.; Ogawa, A. *Tetrahedron Lett.* **1998**, *39*, 5247–5248.

coordinated titanocene(III) in the initial electron transfer from the heterogeneous metal. The nucleophilic intermediate thus generated can be exploited for intramolecular cross-coupling (cyclization) of diketones. At this time, we are engaged in the development of an enantioselective version of this process.

Experimental Section

General Methods. For the reactions using titanocene all solvents and additives were rigorously deoxygenated prior to use. The following known compounds were isolated as pure samples and showed NMR spectra identical to reported data: **2**,[29] **12**,[30] **13**,[31] **14**,[32] **16**,[33] **18**,[34] **19**,[35] **20**,[36] **21**,[36] **22**,[36] **23**,[37] and **24**.[38]

General Procedure for Ti(III)/M(0)-Mediated Reaction. Rigorously deoxygenated THF (20 mL) was added to a mixture of Cp_2TiCl_2 (1.1 mmol) and Mn or Zn dust (8.0 mmol) under Ar atmosphere, and the suspension was stirred at room temperature until it turned green (about 5 min). A solution of carbonyl compound (1.0 mmol), and additive if required, in THF (2 mL) was then added. The mixture was stirred for 1 h (Scheme 1, Table 1, entries 1−4) or 16 h (Table 1, entries 5−10) and then diluted with EtOAc, washed with brine, and dried over anhydrous $MgSO_4$ and the solvent removed. The residue was submitted to flash chromatography (EtOAc/hexane mixtures) to give the corresponding products.

General Procedure for Ti(III)/Mn(0)-Catalyzed Homocoupling Pinacol Reaction. Rigorously deoxygenated THF (15 mL) was added to a mixture of Cp_2TiCl_2 (0.2 mmol) and Mn dust (8.0 mmol) under Ar atmosphere, and the suspension was stirred at room temperature until it turned green (about 15 min). A solution of carbonyl compound (1.0 mmol), 2,4,6-collidine (3.0 mmol), and Me_3SiCl (1.5 mmol) in THF (2 mL) was then added. The mixture was stirred for 16 h and then diluted with EtOAc, washed with 10% aqueous HCl solution and brine, and dried over anhydrous $MgSO_4$ and the solvent removed. The residue was submitted to flash chromatography (EtOAc/hexane mixtures) to give the corresponding products.

Compound 15: yellowish oil; (*dl*) ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10−7.14 (m, 4H), 6.85−6.95 (m, 4H), 2.45 (s, 2H), 1.48 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$, DEPT) δ 162.1 (d, $^1J_{C-F}$ = 245.0 Hz, C), 139.3 (C), 129.3 (d, $^3J_{C-F}$ = 7.0 Hz, CH), 114.0 (d, $^2J_{C-F}$ = 21.0 Hz, CH), 78.8 (C), 25.1 (CH_3); (*meso*) ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.19−7.21 (m, 4H), 1.56 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$, DEPT) δ (only distinctive signals) 128.9 (d, $^3J_{C-F}$ = 7.0 Hz, CH), 78.6 (C), 25.3 (CH_3); ESHRMS calcd for $C_{16}H_{16}O_2F_2Na$ *m*/*z* 301.1010, found *m*/*z* 301.1020).

Compound 17: colorless oil; (*dl*) ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36 (bs, 2H), 6.36 (bs, 2H), 6.24 (bs, 2H), 1.48 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$, DEPT) δ 156.8 (C), 141.8 (CH), 110.5(CH), 107.3(CH), 76.7(C), 22.6(CH_3); (*meso*) ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36 (bs, 2H), 6.24 (bs, 2H), 6.04 (bs, 2H), 1.60 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$, DEPT) δ 156.9 (C), 141.6 (CH), 110.3 (CH), 106.5 (CH), 76.6 (C), 21.7 (CH_3); ESHRMS calcd for $C_{12}H_{14}O_4Na$ *m*/*z* 245.0784, found *m*/*z* 245.0788.

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Supporting Information Available: . Experimental data for control experiments and the synthesis of compounds **12**−**14**. Spectroscopic data and copies of NMR spectra for products described. This material is available free of charge via the Internet at http://pubs.acs.org.

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