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Direct preparation of benzylic manganese reagents from benzyl halides, sulfonates, and phosphates and their reactions: applications in organic synthesis

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Dedicated to Professor Ernst Otto Fischer the pioneer of organometallic chemistry on the occasion of the 85th birthday

Abstract

The use of highly active manganese (Mn)*, prepared by the Rieke method, was investigated for the direct preparation of benzylic manganese reagents. The oxidative addition of the highly active manganese to benzylic halides was easily completed under mild conditions. Moreover, benzylic manganese sulfonates and phosphates were prepared by direct oxidative addition of Mn* to the carbon–oxygen bonds of benzylic sulfonates and phosphates. The resulting benzylic manganese reagents were found to undergo cross-coupling reactions with a variety of electrophiles. Most of these reactions were carried out in the absence of any transition metal catalyst under mild conditions. In addition, the use of highly active manganese was also studied for preparation of homo-coupled products of functionalized benzyl halides without transition metal catalysts. These useful approaches provided not only a facile synthetic route to the preparation of resoricinolic lipids but a facile synthesis of functionalized 4-benzylpyridines by regioselective and chemo selective γ-addition of benzylic group to *N*-alkoxycarbonylpyridinum salts.

Keywords: Manganese; Benzyl manganese reagents; Palladium; Cross-coupling; Homo-coupling

1. Introduction

Benzylic organometallic reagents have been playing an important role in organic synthesis, especially in homologation of organometallics. In spite of their significance, developments of synthetic methods for the preparation of benzylic metal reagents have been limited.

One of the earliest studies of benzylic metal chemistry concerns benzylic lithium reagents. Most benzylic lithium reagents have been prepared via bond cleavage reactions [1] and/or transmetalation reactions [2]. However, in general, these methods are often accompanied by the formation of complex mixtures and homo-coupling products even at low temperature [1]. Similar problems are frequently observed in the preparation of benzylic Grignard reagents. The magnesium anthracene complex involving an electron transfer mechanism has been extensively used to alleviate these problems [3]. In some cases, more efficient direct synthetic methods utilizing the oxidative addition of a metal to the corresponding benzyl halides have been developed including activated zinc [4] and cadmium [5a]. However, a copper catalyst was needed to complete the cross-coupling reaction of benzylic zinc halides with electrophiles. Recently, an interesting new synthetic procedure for preparing benzylic zinc reagent has been reported using triorganozincate and 4-iodobenzyl mesylates [6]. This system appears very useful for the preparation of 4-alkyl substituted benzylic zinc reagents.

Even though some practical synthetic pathways have been developed using active zinc with benzylic halides

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[5b,5c], more facile approaches would be of value to organic synthesis. We now describe an alternative synthetic route for the direct formation of nonfunctionalized and functionalized benzylic manganese halides from the oxidative addition reaction of highly active manganese to benzylic halides [7]. More significantly, benzylic manganese sulfonates and phosphates were prepared by the reaction of Mn* (prepared by the Rieke Method) with the corresponding benzylic sulfonates and phosphates. The resulting benzylic manganese reagents were found to undergo a variety of cross-coupling reactions. It was also found that homo-coupled products of functionalized benzyl halides could be readily prepared depending on reaction conditions.

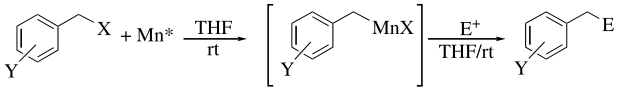
2. Results and discussion

2.1. Preparation and coupling reactions of benzylic manganese halides

Highly activated manganese metal (Mn*) can be prepared via the lithium–naphthalene reduction method in freshly distilled THF at room temperature [8]. Treatment of the highly active manganese (Mn*) with benzyl halides (Br and Cl) gave high yields of the corresponding benzylic manganese halides. The resulting benzylic manganese halides reacted readily with a variety of electrophiles to give the corresponding products. It is worthy to note that most of these coupling reactions were carried out in absence of a transition metal catalyst. The environmental advantage of carrying out these reactions without a transition metal is significant.

While the oxidative addition of Mn* prepared from manganese bromide and chloride to benzyl halides were completed at room temperature in 20 min in THF (Scheme 1), small amounts (3–9%) of homo-coupling products of benzyl halides were observed. However, use of manganese iodide [9] to prepare active Mn* alleviated the problem. Less than 1% of homo-coupling products were formed in these cases.

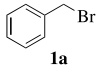
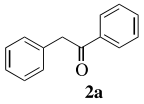
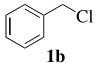
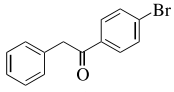
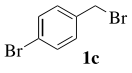
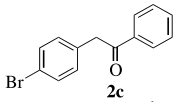
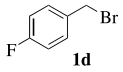
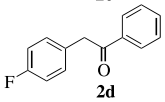
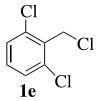
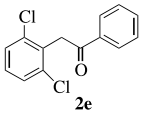
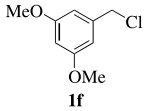
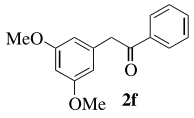
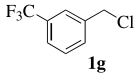
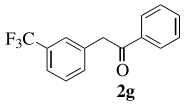
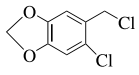
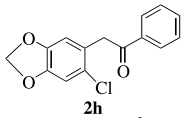
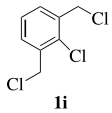
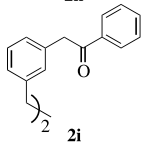
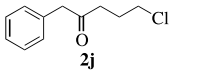
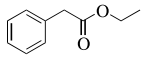
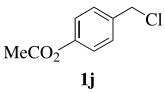
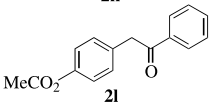
The benzylic manganese halides were reacted with acid chlorides to obtain the cross-coupling products and the results are summarized in Table 1. The cross-coupling reactions with acid chlorides were carried out at room temperature and were completed in 30 min in THF in the absence of any transition metal catalyst



X = Br, Cl
Y = H, Br, Cl, F, OMe, CF_3, CH_3CO_2

Scheme 1.

Table 1
Coupling reaction with acid chlorides

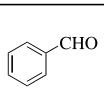
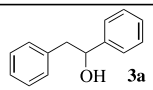
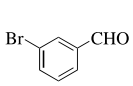
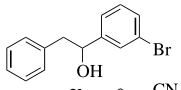
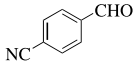
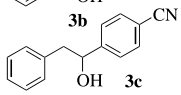
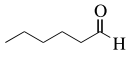
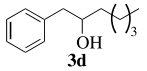
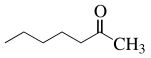
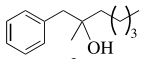
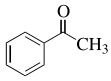
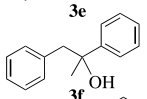
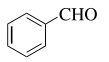
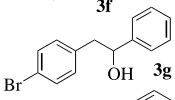
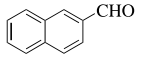
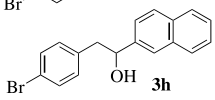
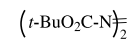
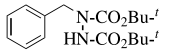
Entry	Halide	Electrophile[b]	Product[c]	Yield (%)[d]
1	 **1a**	**I**	 **2a**	82
2	 **1b**	**I**	**2a**	91
3	**1b**	**II**	 **2b**	85
4	 **1c**	**I**	 **2c**	84
5	 **1d**	**I**	 **2d**	74
6	 **1e**	**I**	 **2e**	75
7	 **1f**	**I**	 **2f**	86
8	 **1g**	**I**	 **2g**	71
9	 **1h**	**I**	 **2h**	89
10	 **1i**	**I**	 **2i**	79
11	**1a**	**III**	 **2j**	78
12	**1b**	**IV**	 **2k**	69
13	 **1j**	**I**	 **2l**	75[e]

[a] Oxidative addition reaction and coupling reaction were carried out at room temperature in THF.
[b] Electrophile; **I** = Benzoyl Chloride, **II** = *p*-Bromobenzoyl Chloride **III** = 4-Chlorobutyryl Chloride, **IV** = Ethyl Chloroformate.
[c] All products were fully characterized by ^1H, ^{13}C NMR and HRMS (or EIMS).
[d] Isolate yield (based on benzyl halides).
[e] 5 mol % CuI was used as a catalyst.

(except entry 13, Table 1). An excess of acid chloride was employed in these reactions to avoid the addition reaction of the remaining benzylic manganese halides to ketones, formed. Both aryl (I, II) and alkyl (III, IV) acid chlorides gave excellent yields (Table 1). Some functionalized benzylic manganese halides (entries 4–9 and 13, Table 1) have been prepared as well as non-functionalized ones (entries 1 and 2, Table 1). Of special interest is entry 8 in Table 1. Preparing oragnometallic reagents with compounds containing a trifluoromethyl group can be problematic. However, **1g** was readily converted to the corresponding organomanganese reagent, and subsequent cross-coupling reaction proceeded in excellent yield. The oxidative addition tolerates an electron-withdrawing group such as a carbomethoxy group (entry 13, Table 1). In contrast to the rest of the entries in Table 1, the manganese derivative of **1j** does not undergo cross-coupling reaction in the absence of catalyst. However, product **2l** readily formed in the presence of a catalytic amount of CuI. Interestingly, treatment of Mn* with α,α′-dichloro-*m*-xylene (**1i**) and the consecutive coupling reaction with benzoyl chloride gave a symmetrical biaryl compounds **2i** in 79% yield (entry 10, Table 1).

The benzylic manganese halides were also found to react with other electrophiles such as aldehydes, ketones, and di-*tert*-butylazodicarboxylate (DBAD). The results are shown in Table 2. Addition to aldehydes (entries 1–4 and 7, Table 2) gave the corresponding secondary alcohols in good yields (78–93%). The reaction tolerated halides or a nitrile group (entry 2 or 3, Table 2) in the aldehyde but not a nitro group. The addition to an alkyl ketone yielded the corresponding tertiary alcohol **3e** in good yield (entry 5, Table 2). But coupling with acetophenone afforded the tertiary alcohol in low yield (entry 6, Table 2). DBAD was also employed as an electrophile, and the corresponding coupling product **3i** was obtained in excellent yield (80%). It should be noted that the coupling reactions described above have been readily accomplished in the absence of any catalyst under mild conditions.

Table 2
Cross-coupling reaction of benzylic manganese bromide

Entry	Halide	Electrophile	Product	Yield (%)[b]
1	**1a**		 **3a**	93
2	**1a**		 **3b**	95
3	**1a**		 **3c**	87
4	**1a**		 **3d**	78
5	**1a**		 **3e**	72
6	**1a**		 **3f**	46
7	**1c**		 **3g**	80
8	**1c**		 **3h**	89
9	**1a**		 **3i**	80

[a] Oxidative addition reaction and coupling reaction were carried out at room temperature in THF.

[b] Isolated yields (based on electrophile)

2.2. Preparation and coupling reactions of benzylic manganese sulfonates and phosphates

In 1992, Yus et al. reported that allyic and benzylic mesylates reacted with lithium naphthalenide to give the corresponding organolithium reagents giving cross-coupling products upon treatment with electrophiles [10,10a].

Considering the high reactivity of the active manganese (Mn*) metal prepared by the Rieke method and the exceptional tolerance to a wide range of functionality in the organic moiety, we explored the possibility of the direct oxidative addition to a variety of carbon–oxygen bonds. Our first approach employed benzyl sulfonates. This was expanded to functionalized and non-functionalized benzylic sulfonates and phosphates later. Benzyl sulfonates and phosphates can be easily prepared from the corresponding alcohols using standard literature procedures [11,12]. Simply stirring the mixture of an alcohol and methane sulfonyl chloride or *p*-toluene sulfonyl chloride in methylene chloride at room temperature in the presence of triethylamine followed by a simple workup procedure yielded the sulfonates in over 80% isolated yields. The synthesis of organophosphates was also easily conducted using the corresponding alcohol and commercially available diethyl chlorophosphate in presence of triethylamine in THF or sodium hydride and diethyl cholorophosphate in THF followed by purification by column chromatography (65% yield). A variety of functionalized benzyl sulfonates and phosphates were prepared by this approach and were used for the preparation of functionalized benzylic manganese reagents. This route provides a significant new approach to benzylic reagents and obviates the need for the corresponding halide, which in many cases is problematic.

Importantly, this study demonstrates that highly active manganese readily undergoes oxidative addition

to carbon–oxygen bonds of benzyl sulfonates and phosphates. Also, the subsequent cross-coupling reactions with a variety of electrophiles can be easily carried out. The synthetic advantages of the approach are apparent considering few reports [13] exist of the oxidative addition of main group or even transition metals to carbon–oxygen bonds. Of particular interest is the availability of tosylates, mesylates and phosphates as precursors to organomanganese reagents (Scheme 2).

Table 3 contains the summarized results of coupling reaction of benzylic manganese sulfonates. The oxidative addition of active manganese to benzyl sulfonates was easily completed at room temperature in only 30 min. According to GC analysis, a small amount ($<8\%$) of homo-coupled product, bibenzyl, was formed during the reaction. The resulting benzylic manganese sulfonates were cross-coupled with several electrophiles. The coupling reactions were completed under mild conditions and significantly in the absence of any transition metal catalyst.

Functionalized benzylic mesylates containing a halogen atom were also investigated. Reactions of the halogenated benzyl manganese mesylates with acid chlorides, aldehydes, and ketones, yielded the corresponding ketone, secondary alcohol, and tertiary alcohol in good to excellent isolate yields as shown in Table 3. As mentioned earlier, it is of interest that the mesylate containing trifluoromethyl group has been successfully employed for the preparation of benzylic manganese mesylate, and the subsequent coupling reaction proceeded in good yield (89%).

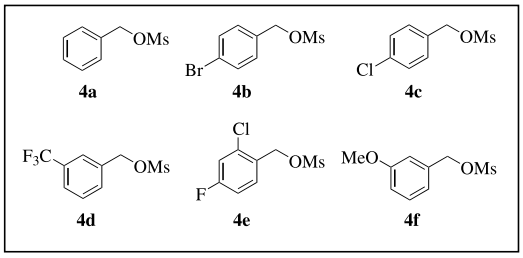
As shown in Table 4, the oxidative addition to alkyl tosylates and coupling reactions of organomanganese tosylates were also investigated. The oxidative addition was easily completed by simple treatment of Mn* with the alkyl tosylates at room temperature in THF.

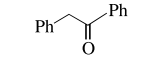
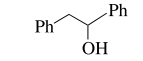
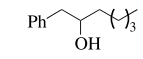
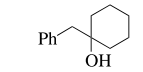
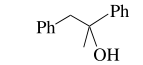
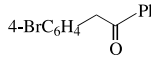
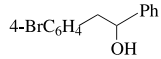
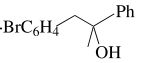
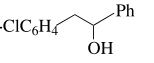
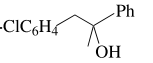
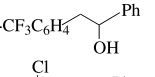
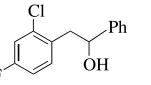
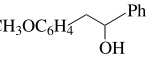
Unfortunately, no oxidative addition was found to occur with phenyl tosylate even at refluxing temperatures (entry 9, Table 4). The formation of organomanganese tosylates was also confirmed by the subsequent cross-coupling reaction with different electrophiles. The tosylates listed in Table 4 reacted with benzoyl chloride to afford the corresponding ketones in moderate to excellent yields (44–86%). Once again, the coupling reaction was carried out at room temperature in THF in the absence of any transition metal catalyst. In contrast to all the primary tosylates, a low yield (17%) was obtained from a secondary tosylate. This may due to the steric hindrance and/or easy elimination of organomanganese tosylate yielding alkenes. Cross-coupling reaction with benzaldehyde also gave the corresponding alcohols in moderate yields (36–64%).

Non-functionalized and functionalized benzyl phosphates were treated with Mn* under the same conditions used for benzyl sulfonates. However, in the case of

Scheme 2.

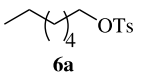
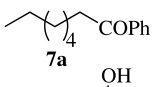
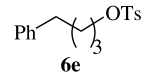
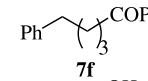
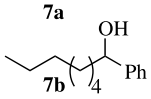
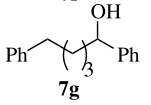
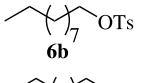
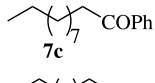
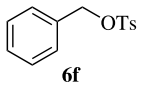
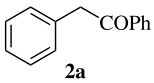
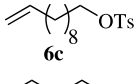
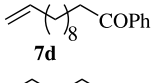
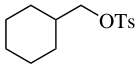
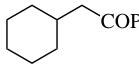
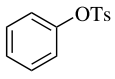
Table 3
Cross-coupling of benzylic and functionalized benzylic manganese sulfonates



Entry	Sulfonates	Electrophiles[a]	Product[b]		Yield (%)[c]
1	**4a**	**I**[d]		**2a**	63[d]
2	**4a**	**II**		**3a**	72
3	**4a**			**3d**	50
4	**4a**			**5a**	29
5	**4a**	$PHCOCH_3$		**3f**	36
6	**4b**	**I**[d]		**2c**	50[d]
7	**4b**	**II**		**3g**	90
8	**4b**	**III**		**5b**	80
9	**4c**	**II**		**5c**	95
10	**4c**	**III**		**5d**	92
11	**4d**	**II**		**5e**	89
12	**4e**	**II**		**5f**	92
13	**4f**	**II**		**5g**	94

[a] Electrophiles; **I**: Benzoyl Chloride, **II**: Benzaldehyde, **III**: Acetophenone
[b] All of the products were fully characterized by ^1H, ^{13}C NMR, FTIR and HRMS.
[c] Isolate yields (based on electrophiles unless otherwise mentioned. [d] Excess benzoyl chloridewas used (yield was based on mesylate).

Table 4
Preparation of organomanganese tosylates and their coupling reaction

Entry	Tosylate	E[a]	Product	Yield(%)[b]	Entry	Tosylate	E[a]	Product	Yield(%)[b]
1	 **6a**	I	 **7a**	48	6	 **6e**	I	 **7f**	48
2	**6a**	II	 **7b**	64	7	**6e**	II	 **7g**	36
3	 **6b**	I	 **7c**	57	8	 **6f**	I	 **2a**	74[c]
4	 **6c**	I	 **7d**	44					
5	 **6d**	I	 **7e**	86	9	 **6g**		-	0[d]

[a] Electrophile; **I** : Benzoyl chloride, **II** : Benzaldehyde.

[b] Based on electrophile unless otherwise mentioned.

[c] Excess benzoyl chloride was used(yield was based on tosylate).

[d] No oxidative addition was occured.

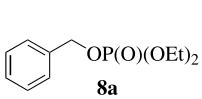
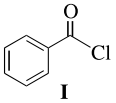
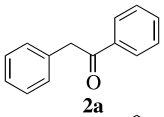
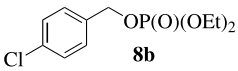
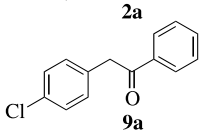
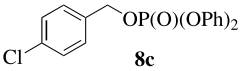
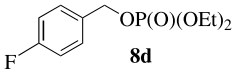
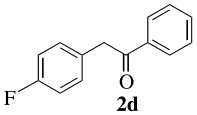
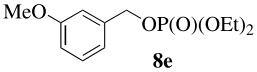
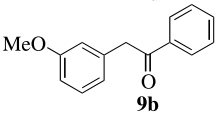
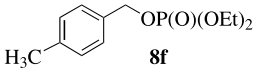
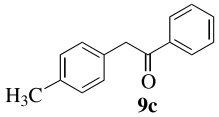
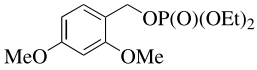
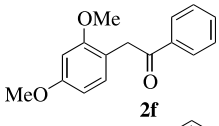
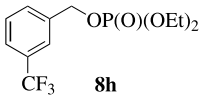
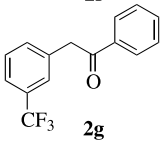
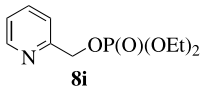
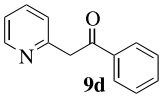
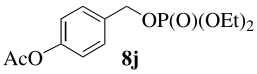
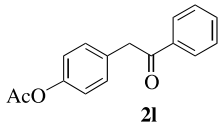
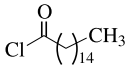
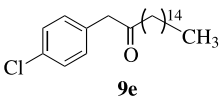
benzyl phosphates, a longer reaction time was required to complete the oxidative addition compared to the cases of benzyl mesylate and tosylate. The oxidative addition of Mn* to the C–O bond of the phosphate was completed after being stirred at room temperature overnight (8 h). According to GC and TLC analysis, a trace amount of homo-coupling product was observed. The subsequent coupling reactions of the resulting benzylic manganese phosphates with acid chlorides, benzaldehydes, and ketones, gave the corresponding products in moderate to good yields at room temperature in dry THF in the absence of any transition metal catalyst. To facilitate the oxidative addition to the organophosphates, use of a sonicator or increase of reaction temperature was examined. But, this resulted in the formation of un-expected side products and was not continued. The results of the coupling reactions of nonfunctionalized as well as functionalized benzylic manganese phosphates with acid chlorides are summarized in Table 5. These results indicate that a wide range of functional groups can be tolerated under these conditions. The ethyl groups in the starting phosphate were replaced with phenyl groups with little or no effect on the overall reaction (entries 2 and 3, Table 5). In contrast to all the rest of the entries in Table 5, the manganese derivatives of **8j** do not undergo cross-coupling without Cu catalyst. In the presence of CuI, product **2l** was obtained in 39% yield.

The benzylic manganese phosphates were also found to react with other electrophiles including aldehydes and ketones. The results are summarized in Table 6. Addition to aldehydes gave the corresponding secondary alcohols in moderate yield (38–76%). However, the addition reaction to acetophenone afforded the tertiary alcohol in low yield (19%). The reaction tolerated a nitrile group in the aldehyde (entry 8, Table 6), but not a nitro group. When *p*-cyanobenzyl diethyl phosphate was treated with Mn*, only the homo-coupled product was observed under a wide range of reaction conditions.

To expand the range of phosphates for preparation of organomanganese phosphates, alkyl-, phenyl-, and allyl diethyl-phosphates were attempted. Unfortunately, the oxidative addition of active manganese (Mn*) to these phosphates and the subsequent coupling reactions with electrophiles failed to give the corresponding cross-coupled products.

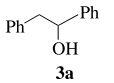
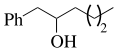
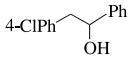
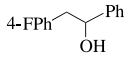
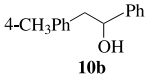
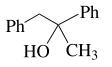
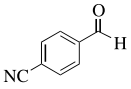
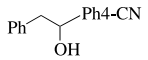
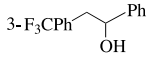
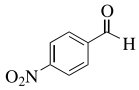
Overall, the isolated yields obtained from using benzyl sulfonates and phosphates were lower than those from using benzyl halides. At this time, we do not understand fully why the manganese halides give better yields than the manganese sulfonates or phosphates. However, this unusual oxidative addition to C–O bond of benzyl sulfonates, and phosphates under mild condition and the resulting organomanganese reagents provide a new synthetic route to benzylic manganese reagents. Moreover, to our knowledge, these are the first examples of organomanganese sulfonates and phosphates prepared via direct oxidative addition of manganese metal or by any methasis approach.

Table 5
Coupling reactions of benzylic manganese phosphates with acid chlorides

Entry	Phosphates	Electrophiles	Product[b]	Yield(%)[c]
1	 **8a**	 **I**	 **2a**	52[d]
2	 **8b**	**I**	 **9a**	45
3	 **8c**	**I**	**9a**	47
4	 **8d**	**I**	 **2d**	51
5	 **8e**	**I**	 **9b**	58[d]
6	 **8f**	**I**	 **9c**	72
7	 **8g**	**I**	 **2f**	72
8	 **8h**	**I**	 **2g**	49
9	 **8i**	**I**	 **9d**	54[d]
10	 **8j**	**I**	 **2l**	39[e]
11	**8k**		 **9e**	62[f]

[a] Oxidative addition reactions and coupling reactions were carried out at rt in THF.
[b] All products were fully characterized by ^{1}H,^{13}C NMR and/or HRMS(EIMS).
[c] Isolated yields (based on Electrophiles). [d] Excess benzoyl Chloride was used (yield was based on Phosphate). [e] 5 mol % CuI was used as a catalyst. [f] the yield after recrystallization over hexanes.

Table 6
Addition reactions of benzylic manganese phosphates

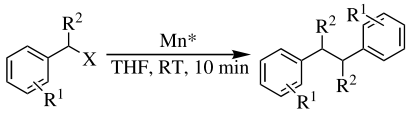
Entry	Phosphates	Electrophiles	Product	Yield(%)[b]
1	**8a**	 **II**	 **3a**	73
2	**8a**		 **3d**	49
3	**8b**	**II**	 **5c**	38
4	**8d**	**II**	 **10a**	44
5	**8f**	**II**	 **10b**	52
6	**8a**	Acetophenone	 **3f**	19
7	**8a**		 **3c**	76
8	**8h**	**II**	 **5e**	46
9	**8a**		-	0[c]

[a] Oxidative addition reactions and cross-coupling reactions were carried out at room temperature in THF. [b] isolated yield (based on electrophile). [c] According to TLC and/or GC analyses, no coupling reaction was occured.

2.3. Homo-coupling reaction of functionalized benzylic manganese reagents

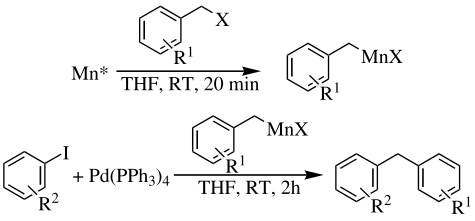
We examined the homo-coupling of benzyl halides under the influence of active manganese in a wide variety conditions.

As shown in Table 7, one equivalent of active manganese and two equivalents of benzyl bromide produced 47% of homo-coupling products. But the homo-coupling yield was decreased to 27% by using one equivalent of benzyl bromide.



R^1 = CN, H, CO_2Me, NO_2, Br, Cl, OMe, CH_3
R^2 = H, CH_3
X = Br, Cl

Scheme 3.



R^1 = H, Br, Cl, OMe
R^2 = CO_2Et, CN
X = Br, Cl, $OP(O)(OEt)_2$

Scheme 4.

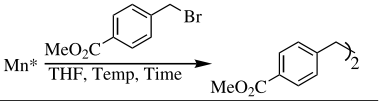
Best results were obtained when the active manganese was added to the neat benzyl bromide. The reaction was completed within 10 min at room temperature without a catalyst [14]. Several other benzyl halides produced good to excellent yields of homo-coupling products, which showed a wide tolerance of functional groups such as nitrile, ester, nitro, chloro, bromo, methoxy, and methyl group (Table 8).

Our method is more efficient compared to the previous attempts to prepare functionalized bibenzyl compounds [15] in terms of milderness and speed of the reaction. More significantly, no transition metal catalyst (Pd or Ni) was required for completion of the reaction nor was a solvent required.

2.4. Palladium-catalyzed cross-coupling reaction of benzylic manganese reagents

Cross-coupling reactions of alkyl organometallic compounds with alkyl or aryl halides are difficult to perform because of the slow oxidative addition of alkyl halides to the palladium and slow reductive elimination of dialkyl or alkyl–aryl products. Only limited examples

Table 7
Homo-coupling reactions of benzyl bromides at different reaction conditions



Entry	Mn* : $ArCH_2Br$	Temp	Time	Yield[a]
1	1.00 : 1.99	RT	3H	47
2	1.00 : 0.90	RT	30 min	27
3	1.00 : 1.91	RT	10min	68[b]
4	1.00 : 1.90	0 °C	30 min	60
5	1.00 : 1.80	RT	10 min	80[c]

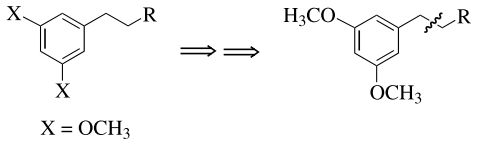
[a] Isolated yields. [b] The benzyl bromide was slowly added to the active manganese for 30 min with 10 ml of THF. [c] THF solution of active manganese was added to the benzyl bromide.

Table 8
Homo-coupling reactions of benzyl halides

Entry	R^1	R^2	X	Product	Yield [a]
1	4-CN	H	Br	**11a**	82
2	3-CN	H	Br	**11b**	90
3	2-CN	H	Br	**11c**	84
4	H	CH_3	Br	**11d**	85
5	4-CO_2Me	H	Br	**11e**	80
6	4-NO_2	H	Br	**11f**	34 [b]
7	4-Br	H	Br	**11g**	60 [c]
8	4-Cl	H	Cl	**11h**	65 [c]
9	2,6-*di*Cl	H	Cl	**11i**	77 [c]
10	3,5-*di*OMe	H	Cl	**11j**	70 [c]
11	2-CH_3	H	Cl	**11k**	59 [c]

[a] Isolated yields.
[b] 0.64 equivalents of $ArCH_2X$ was used.
[c] Yields obtained after recrystallization over hexanes.

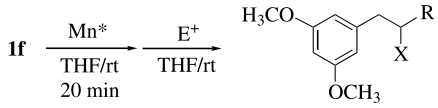
are reported for the cross-coupling of the benzyl



X = OCH_3

A X = OH

Scheme 5.



Scheme 6.

organometallic compounds with aryl halides. Betzemeier and Knochel [4a] reported the palladium catalyzed cross-coupling of benzylzinc bromides with aryl iodides in perfluorinated solvents and Park et al. [16] prepared diarylmethanes from benzylmagnesium chlorides and aryl bromides with nickel catalyst. Yoshida et al. [17] prepared functionalized diarylmethanes from cross-coupling reactions of (2-pyridyl)silylmethylstannanes and aryl iodides with a palladium catalyst and additive. The above-mentioned methods required additives and long reaction times and in some cases they did not tolerate functional groups.

Benzylic manganese halides and phosphates were also found to undergo palladium-catalyzed cross-coupling reactions with aryl iodides (sp^3–sp^2 coupling). As Shown in Schemes 3 and 4 (Table 9), the corresponding cross-coupling compounds were achieved in moderate to good yields using 5 mol.% palladium catalyst [$Pd(PPh_3)_4$] in THF within 2 h at room temperature.

2.5. Applications

As described above, the benzylic manganese reagents have been found to undergo reactions with aldehydes and acid chlorides under mild conditions. Interestingly, this approach can be easily applied to the preparation of resorcinolic lipid precursors. Resorcinolic lipids of the general type A are mainly isolated from plants as presented below. In general, 5-*n*-alkylresorcinols have shown a variety of biological activities including antimicrobial, antiparasitic, cytotoxic activity, growth regulator, and DNA cleaving properties [18]. As shown in Scheme 5, the key step in this synthesis is the C–C bond formation. The C–C bond can be obtained by the reaction of an arylmetallic reagents with alkyl substrates (or vice versa) followed by the reduction of functional groups to give rise to the alkyl chains.

To this end, a few synthetic methods have been reported for the preparation of 5-*n*-alkylresorcinols. These methods include the use of 3,5-dimethoxybenzaldehyde [19], 3,5-dimethoxy-benzylic alcohol [20], and 3,5-dimethoxyphenol [21]. Until recently, because of the difficulty of the preparation of benzylic metal reagents [22], only one resorcinol, olivetol, has been prepared using 3,5-dimethoxybenzylic magnesium chloride [23].

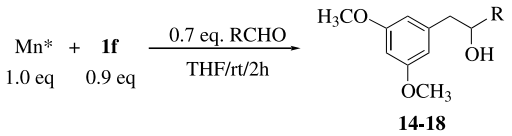
As already reported, cross-coupling reactions of benzylic manganese chloride with aldehydes and acid chlorides readily afforded the corresponding coupling products. Therefore, we can apply this approach to the preparation of 5-*n*-alkylresorcinols and/or their precursors.

Cross-coupling reactions of 3,5-dimethoxybenzylic manganese chloride with alkyl aldehydes and acid chlorides were carried out at room temperature in absence of any catalyst to give the corresponding

Table 9
Palladium catalyzed cross-coupling reactions of benzyl manganese halides and phosphate with aryl iodides

Entry	R^1	R^2	X	Product	Yield [a]
1	H	4-CO_2Et	Br	**12a**	78
2	4-Br	4-CO_2Et	Br	**12b**	56
3	3,5-*di*OMe	3-CN	Cl	**12c**	40
4	4-Cl	4-CO_2Et	Cl	**12d**	64
5	4-Cl	4-CO_2Et	$OP(O)(OEt)_2$	**12d**	40

[a] Isolated yields.



Scheme 7.

coupling products (**13a**–**d**), respectively in excellent isolated yields. All of the compounds listed in Scheme 6 can be used as intermediates for the preparation of 5-*n*-alkylresorcinols [24,30].

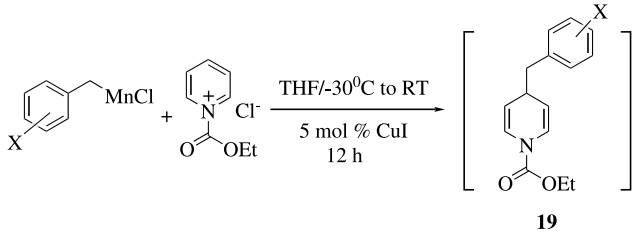
Furthermore, as shown in Scheme 7, simple coupling reactions of **1f** with aryl aldehydes yielded the coupling products in excellent isolated yields under mild conditions. It should be noted that this approach provides a more facile route than using benzyloxytrimethylsilane [20] in terms of the yield.

Another convenient approach to a synthesis of functionalized 4-benzylpyridines becomes feasible because of the facile synthetic route to benzylic manganese reagents.

A few methods have been developed for the reioselective introduction of a carbon substituent in the four-position of a pyridine ring: organocopper reagents [25], silyl enol ethers [26], and titanium enolates [27] attack regioselectively the γ-position of *N*-alkyl-carbonylpyridium salts to give 4-substituted 1,4-dihydropyridines. More recently, Yamaguchi et al. [28] reported that a very expensive benzyltin reagent could be added to the four position of a pyridine ring. And also, use of mixed copper, zinc benzylic organometallics for regio- and chemoselective addition to functionalized pyridium salts has been reported [4e].

In view of the feasibility and the high reactivity of benzyl manganese reagents, we examined the reactivity of benzyl nucleophiles towards pyridium salts. Interestingly, it was found that the reaction of *N*-ethoxycarbonylpyridium chloride, prepared in situ from ethyl chloroformate and pyridine, with benzyl as well as substituted benzyl organometallics proceeded smoothly with high γ-selectivity at room temperature to obtain regioselectively 4-benzylpyridines after oxidation in good yield (Scheme 8).

However, it should be noted that in the absence of a Cu catalyst, the addition reaction of benzyl manganese reagents did not take place. CuI (5 mol.%) was used as a



Scheme 8.

catalyst for the addition reaction. The intermediate, 1,4-dihydropyridines, were found to be somewhat stable in air at room temperature. On exposure to oxygen for more than 8 h or to sulfur in decalin under reflux, the intermediate compounds (**19**) were readily oxidized to the corresponding 4-benzylpyridines. Therefore, our method provides an easy access to the synthesis of functionalized 4-benzylpyridines. More interestingly, this approach provides a regio- and chemo-selective synthesis of functionalized 1,4-dihydro-pyridines, which have been shown to be biologically important substances as well as useful synthetic intermediates for nitrogen heterocycles [29].

2.6. Limitations of this approach

A number of different types of benzyl substrates, diethyl benzylphosphonate, benzyl methyl sulfide, benzyl phenyl sulfide, benzyl benzoate, benzyl phenyl ether, and benzyloxytrimethylsilane were also reacted with Mn*. Unfortunately, according to TLC and/or gas chromatography analyses, no oxidative addition occurred with these substrates.

As shown in previous tables containing cross-coupling products, a number of different types of electrophiles were used to complete the cross-coupling reaction of benzylic manganese reagents prepared via direct oxidative addition of Mn* to the corresponding benzylic halides, sulfonates, and phosphates. Apparently, functional group tolerance is a big advantage of this system. However, no coupling products were obtained from the coupling reactions with the following substarates: *p*-nitrobenzaldehyde, epoxides, ester and alkyl cyanides.

3. Experimental

3.1. General methods

^{1}H-NMR (300 MHz) spectra were recorded in $CDCl_3$ solution. All chemical shifts are reported in parts per million (δ). Fully decoupled ^{13}C-NMR (75 MHz) spectra were recorded in $CDCl_3$ solution. Tetramethylsilane was used as a reference in ^{1}H-NMR experiments and the center peak of $CDCl_3$ (77.7 ppm) was used as the internal reference in ^{13}C-NMR experiments.

All manipulations were carried out under argon on a dual manifold of vacuum/argon system. The Linweld prepurified grade argon was further purified by passage over a BASF R3-11 catalyst column at 150 °C, a phosphorus pentoxide column, and a column of granular potassium hydroxide. Lithium, naphthalene, and manganese halides were weighed out and charged into reaction flasks under argon in a Vacuum Atmospheres Company drybox. Tetrahydrofuran was distilled immediately before use from Na/K alloy under argon.

Gas chromatographic analyses were done on a Hewlett–Packard 6890 chromatograph using HP-5 cross-linked 5% phenyl methyl siloxane column (0.32 mm × 30 M). Analytical thin-layer chromatography was performed using Merck 5735 indicating plates precoated with silica gel 60 F254 (layer thickness 0.2 mm). The product spots were visualized with either UV lamp or a phosphomolybdic acid reagent (20 wt.% solution in ethyl alcohol). Liquid chromatographic purification was performed by flash column chromatography using glass columns packed with Merck silica gel 60 (230–400 mesh).

3.2. Preparation of highly active manganese (Mn*)

To the mixture of lithium (4.4 mmol), naphthalene (0.4 mmol), and manganese halides (2 mmol) was added via syringe freshly distilled THF (10 ml) at room temperature (r.t.) and then the resulting mixture was allowed to stir at r.t. for 1 h. The black slurry was obtained and ready for use. (Note: the number of millimoles of Mn* cited in this paper refers to the theoretical amount possible based on the original amount of anhydrous manganese halide.) No attempt was made to determine whether the Mn*, either wet as slurry or pre-dried, was pyrophoric. However, it should be treated as if it is pyrophoric and kept under argon at all times.

3.3. Typical preparation of benzylic manganese halides and their coupling reactions with benzoyl chlorides to give ketones (**2a**–**l**)

Benzyl halide (9 mmol) in THF (2 ml) was added via a cannula to the slurry of highly active manganese (10 mmol) being stirred in THF (15 ml) at r.t. The slurry was stirred at r.t. for 20 min. The reaction was monitored by gas chromatography. After the completion of the oxidative addition, the mixture was cooled to 0 °C. 1,2-Dibromoethane was added to the mixture at this temperature to react with the excess Mn*, and the mixture was stirred for 5 min. The resulting mixture was transferred via cannula to the benzoyl chloride solution in THF at r.t. After being stirred for 30 min, the mixture was quenched with 3 M HCl solution and extracted with diethyl ether. The combined organic layers were washed with $NaHCO_3$, $Na_2S_2O_3$, and brine, dried over anhydrous $MgSO_4$, and concentrated using a rotary evaporator. Flash column chromatography (ethyl acetate/hexanes) afforded the corresponding ketones.

3.3.1. Benzyl phenyl ketone (**2a**)

White solid; m.p.: 55–56 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.31$ (s, 2H), 8.05–7.28 (m, 10H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 45.43$, 126.83, 128.53, 128.60, 129.41, 133.10, 134.48 136.54, 197.55 ppm.

3.3.2. Benzyl 4-bromophenyl ketone (**2b**)

White solid; m.p.: 112–113 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.26$ (s, 2H), 8.02–7.24 (m, 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 45.47$, 127.00, 128.33, 128.74, 129.33, 130.10, 131.92, 132.35, 134.09, 135.20, 196.54 ppm.

3.3.3. 4-Bromobenzyl phenyl ketone (**2c**)

White solid; m.p.: 147–148 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.25$ (s, 2H), 8.02–7.13 (m, 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 44.67$, 120.89, 128.44, 128.68, 131.22, 131.66, 133.32, 133.39, 136.30, 196.92 ppm.

3.3.4. 4-Fluorobenzyl phenyl ketone (**2d**)

White solid; m.p.: 108–110 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.26$ (s, 2H), 8.02–7.00 (m, 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 44.41$, 115.34, 115.52, 128.45, 128.64, 130.12, 130.15, 130.96, 131.02, 132.21, 136.46, 160.88, 162.84, 197.29 ppm.

3.3.5. 2,6-Dichlorobenzyl phenyl ketone (**2e**)

White solid; m.p.: 70–80 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.72$ (s, 2H), 8.11–7.20 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 41.32$, 127.92, 128.15, 128.69, 128.76, 132.13, 133.36, 136.11, 194.54 ppm.

3.3.6. 3,5-Dimethoxybenzyl phenyl ketone (**2f**)

White solid; m.p.: 60–61 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.77$ (s, 6H), 4.22 (s, 2H), 8.03–6.35 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 45.79, 55.25, 98.89, 107.46, 128.60, 133.15, 136.51, 136.67, 146.68, 160.90, 197.39 ppm. HRMS Calc. for $C_{16}H_{16}O_3$ 256.1099, Found: 256.1100.

3.3.7. Phenyl 3-trifluoromethylbenzyl ketone (**2g**)

Pale yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.37$ (s, 2H), 8.05–7.45 (m, 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 44.77$, 123.73, 123.77, 123.83, 126.33, 126.38, 128.37, 128.72, 128.92, 133.09, 133.44, 135.33, 136.27, 196.56 ppm.

3.3.8. 6-Chloropiperonyl phenyl ketone (**2h**)

Pale yellow Solid; m.p.: 124–125 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 4.34$ (s, 2H), 5.96 (s, 2H), 8.06–6.72 (m, 7H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 42.92$, 101.72, 109.80, 110.86, 125.74, 125.97, 128.27, 128.63, 133.25, 136.49, 146.4, 147.39, 196.4 ppm. HRMS Calc. for $C_{15}H_{11}ClO_3$ 274.0397, Found: 274.0401.

*3.3.9. 1,2-di-(3′-Benzylmethylphenyl)ethane (**2i**)*

White solid; m.p.: 131–132 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.88$ (s, 4H), 4.25 (s, 2H), 8.03–7.04 (m, 18H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 37.71, 45.46, 127.03, 128.60, 129.58, 133.10, 134.48, 136.62, 142.10, 197.71 ppm. HRMS Calc. for $C_{30}H_{26}O_2$ 418.1933, Found: 418.1928.

*3.3.10. 5-Chloro-1-phenyl-2-pentanone (**2j**)*

Pale brown oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.08$ (q, $J = 6.60$ Hz, 4H), 2.64 (t, $J = 6.60$ Hz, 2H), 3.51 (t, $J = 6.60$ Hz, 2H), 3.69 (s, 2H), 7.33–7.17 (m, 5H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 27.39$, 43.88, 44.13, 29.92, 126.84, 128.52, 129.17, 133.86, 206.80 ppm.

*3.3.11. Ethyl phenylacetate (**2k**)*

Pale yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.31$ (t. $J = 7.15$ Hz, 3H), 3.67 (s, 2H), 4.22 (q, $J =$ 7.15 Hz, 2H) ppm. ^{13}C–NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.05$, 41.29, 60.67, 126.90, 128.42, 129.11, 134.08, 171.42 ppm.

*3.3.12. 4-Carbomethoxybenzyl phenyl ketone (**2l**)*

White solid; m.p.: 131–132 93–94 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.29$ (s, 3H), 4.28 (s, 2H), 8.03–7.05(m. 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 21.05$, 44.61, 121.66, 128.57, 128.63, 130.43, 131/98, 133.22, 136.42, 149.53, 169.39, 197.26 ppm.

*3.4. Alcohols from the reactions of benzylic manganese halides with aldehydes and ketones (**3a**–**i**)*

Benzyl halide (9 mmol) in THF (2 ml) was cannulated to the slurry of highly active manganese (10 mmol) being stirred in THF (15 ml) at r.t. The slurry was stirred at r.t. for 20 min. The reaction was monitored by gas chromatography. After the completion of the oxidative addition, the mixture was cooled to 0 °C. 1,2-Dibromoethane was added to the mixture at this temperature, and the mixture was stirred for 5 min. To the resulting mixture was added aldehydes (or ketone) at r.t. After being stirred for 1 h, the mixture was quenched with 2 M HCl solution and extracted with diethyl ether. The combined organic layers were washed with $NaHCO_3$, $Na_2S_2O_3$, and brine, dried over anhydrous $MgSO_4$, and concentrated using a rotary evaporator. Flash column chromatography (ethyl acetate/hexanes) afforded the corresponding alcohols.

*3.4.1. 1,2-Diphenylethanol (**3a**)*

Pale-yellow solid; m.p.: 64–65 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.04$ (s, 1H), 3.02–3.06 (m, 2H), 4.91, (dd, $J = 5.10$, 5.10 Hz, 1H), 4.92, 7.21–7.39 (m, 10H) ppm. ^{13}C-NMR: 46.01, 75.26, 125.85, 126.54, 127.54, 128.34, 128.43, 129.46, 137.99, 143.76 ppm.

*3.4.2. 1-(3-Bromophenyl)-2-phenylethan-1-ol (**3b**)*

Pale-brown oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.07$ (s, 1H), 2.90–3.06 (m, 2H), 4.84 (dd, $J = 4.80$, 4.80 Hz, 1H), 4.92, 7.19–7.55 (m, 9H) ppm. ^{13}C-NMR: $\delta = 46.01$, 74.52, 122.49, 124.49, 126.77, 128.56, 128.95, 129.45, 129.90, 130.5, 137.42, 146.04 ppm. HRMS Calc. for $C_{14}H_{13}O$ Br 276.0150; Found: 258.0051[$M^+ - H_2O$], 276.0150 [M^+].

*3.4.3. 1-(4′-Cyanophenyl)-2-phenylethan-1-ol (**3c**)*

White solid; m.p.: 66–67 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.43$ (s, 1H), 2.98 (m, 2H), 4.92 (dd, $J = 5.25$, 5.48 Hz, 1H), 4.94, 7.13–7.61 (m, 9H) ppm. ^{13}C-NMR: 45.3, 74.35, 11.92, 118.75, 126.49, 126.81, 128.52, 129.39, 132.02, 136.81, 148.98 ppm. HRMS Calc. for $C_{15}H_{13}NO$ 223.0997; Found: 205.0889 [$M^+ - H_2O$).

*3.4.4. 1-Phenylheptan-2-ol (**3d**)*

Pale-yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.92$ (t, $J = 6.60$ Hz, 3H), 1.33–1.54 (m, 8H), 1.60 (s, 1H), 2.62–2.87 (m, 2H), 3.82 (m, 1H), 7.22–7.35 (m, 5H) ppm. ^{13}C-NMR: δ 14.00, 22.59, 25.39, 31.82, 36.73, 44.00, 72.63, 126.35, 128.47, 129.38, 138.65 ppm.

*3.4.5. 2-Methyl-1-phenylheptan-2-ol (**3e**)*

Pale-yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.93$ (t, $J = 7.16$ Hz, 3H), 1.16 (s, 3H), 1.29–1.47 (m, 10H), 2.77 (dd, $J = 33.62$, 6.91 Hz, 2H), 7.2–7.35 (m, 5H) ppm. ^{13}C-NMR: δ 14.03, 22.65, 23.67, 26.45, 32.36, 41.80, 47.92, 72.48, 126.35, 128.11, 130.51, 137.60 ppm. HRMS Calc. for $C_{14}H_{22}O$ 206.1671; Found: 188.1563 [$M^+ - H_2O$], 191.1434 [$M^+ - CH_3$].

*3.4.6. 2,3-Diphenylpropan-2-ol (**3f**)*

Pale-yellow solid; m.p.: 49–50 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.60$ (s, 3H), 1.92 (s, 1H), 3.10 (dd, $J = 20.27$, 46.73 Hz, 2H), 7.02–7.45 (m, 10H) ppm. ^{13}C-NMR: δ 29.32, 50.45, 74.39, 124.93, 126.61, 128.01, 130.57, 136.70, 147.51 ppm.

*3.4.7. 2-(4′-Bromophenyl)-1-phenylethan-1-ol (**3g**)*

Pale-yellow solid; m.p.: 39–40 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.04$ (s, 1H), 2.98 (d, $J =$ 6.44 Hz, 2H), 4.85 (t, $J = 6.67$ Hz, 1H), 7.03–7.43 (m, 9H) ppm. ^{13}C-NMR: δ 45.15, 75.10, 120.41, 125.84, 127.73, 128.43, 131.22, 131.38, 136.96, 143.46 ppm.

*3.4.8. 2-(4′-Bromophenyl)-1-(2′-naphthyl)ethan-1-ol (**3h**)*

White solid; m.p.: 96–97 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.18$ (d, $J = 8.58$ Hz, 1H), 3.05 (d, $J = 6.44$ Hz, 2H), 5.00 (t, $J = 6.44$ Hz, 1H), 7.04–7.88 (m, 11H) ppm. ^{13}C-NMR: δ 45.03, 75.19, 120.44, 123.92, 124.62, 125.93, 126.19, 127.66, 127.94, 128.24, 131.24, 131.41, 132.96, 133.15, 136.89, 140.83 ppm.

*3.4.9. N-Benzylhydrozoinodicarboxylic acid di-tert-butyl ester (**3i**)*

Pale-yellow solid; m.p.: 102–104 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.45$, 1.49 (ss, 18H), 4.64 (s, 2H), 6.25 (br s, 1H), 7.27–7.33 (m, 5H) ppm. ^{13}C-NMR: δ 28.12, 28.20, 81.17, 127.48, 128.46, 128.60, 128.68, 159.30 ppm.

3.5. Typical procedure for the cross-coupling reactions of benzyl manganese sulfonates

Benzyl mesylate (9 mmol) was added via a syringe to the slurry of active manganese (10 mmol) being stirred in THF (10 ml) at r.t. The resulting mixture was stirred at r.t. for 20 min. The reaction was monitored by gas chromatography. After the completion of the oxidative addition, the mixture was cooled to 0 °C. 1,2-Dibromoethane was added to the mixture at this temperature, and the mixture was stirred for 5 min. Benzoyl chloride was added to the resulting mixture at r.t. After being stirred for 30 min, the mixture was quenched with 2 M HCl solution and extracted with diethyl ether. The combined organic layers were washed with $NaHCO_3$, $Na_2S_2O_3$, and brine, dried over anhydrous $MgSO_4$, and concentrated using a rotary evaporator. Flash column chromatography (ethyl acetate/hexanes) afforded the corresponding ketones.

*3.5.1. 1-Benzylcyclohexan-1-ol (**5a**)*

Pale-yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.26$ (m, 8H), 1.39 (t, 4H), 2.76 (s, 2H), 7.08–7.22 (m, 5H) ppm. ^{13}C-NMR: δ 18.75, 27.87, 38.06, 46.88, 69.26, 125.78, 128.33, 139.48 ppm.

*3.5.2. 3-(4′-Bromophenyl)-2-phenylpropan-2-ol (**5b**)*

Pale-brown oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.59$ (s, 3H), 3.04 (q, $J = 13.50$ Hz, 2H), 6.85–7.41 (m, 9H) ppm. ^{13}C-NMR: δ 29.18, 49.78, 74.33, 120.56, 124.88, 126.74, 128.04, 130.90, 132.20, 135.77, 147.00 ppm.

*3.5.3. 3-(4′-Bromophenyl)-2-phenylpropan-2-ol (**5c**)*

Pale-yellow solid; m.p.: 55-56 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.14$ (d, $J = 4.20$ Hz, 1H), 2.99 (d, $J = 6.90$ Hz, 2H), 4.84 (t, $J = 6.60$ Hz, 1H), 7.08–7.36 (m, 9H) ppm. ^{13}C-NMR: δ 45.03, 75.13, 125.81, 127.67, 128.39, 130.80, 132.26, 136.41, 143.45 ppm.

*3.5.4. 3-(4′-Chlorophenyl)-2-phenylpropan-2-ol (**5d**)*

Pale-brown oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.58$ (s, 3H), 1.89 (br s, 1H), 3.05 (q, $J = 13.50$ Hz, 2H), 6.90–7.41 (m, 9H) ppm. ^{13}C-NMR: δ 29.23, 49.74, 74.40, 124.89, 126.76, 127.98, 128.05, 131.81, 132.42, 135.24, 147.04 ppm. HRFAB Calc. for $C_{15}H_{15}ClO$ 246.0811, Found: $[M+Li]^+$ 253.0969.

*3.5.5. 2-(3′-Trifluoromethylphenyl)-1-phenylethan-1-ol (**5e**)*

Pale-yellow oil. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.14$ (s, 1H), 3.08 (m, 2H), 4.87, 4.89 (dd, $J = 5.96$, 5.72 Hz, 1H), 7.31–7.52 (m, 9H) ppm. ^{13}C-NMR: δ 45.41, 75.05, 123.27 (q), 125.80, 126.19 (q), 127.80, 128.44, 128.62, 132.94, 139.00, 143.36 ppm. HRFAB Calc. for $C_{15}H_{13}F_3O$ 266.0918, Found: $[M+Li]^+$ 273.1076.

*3.5.6. 2-(2′-Chloro-4′-fluorophenyl)-1-Phenylethan-1-ol (**5f**)*

Pale-yellow solid; m.p.: 64–66 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.39$ (br s, 1H), 3.03–3.18 (m, 2H), 4.93, 4.96 (dd, $J = 5.25$, 5.01 Hz, 1H), 6.86–7.36 (m, 9H) ppm. ^{13}C-NMR: δ 42.68, 73.30, 113.56, 113.83, 116.44, 116.76, 125.64, 127.64, 128.36, 131.76, 131.81, 132.69, 132.81, 134.53, 134.66, 143.62, 159.58, 162.87 ppm. HRFAB Calc. for $C_{14}H_{12}ClFO$ 250.0561, Found: $[M+Li]^+$ 257.0729.

*3.5.7. 2-(3′-Methoxyphenyl)-1-phenylethan-1-ol (**5g**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.24$ (s, 1H), 3.00, 3.03 (dd, $J = 3.10$, 5.96 Hz, 2H), 3.78 (s, 3H), 4.88, 4.91 (dd, $J = 5.48$, 5.45 Hz, 1H), 6.75–7.39 (m, 8H) ppm. ^{13}C-NMR: δ 45.98, 54.99, 75.06, 111.98, 114.95, 121.72, 125.81, 127.45, 128.27, 129.33, 139.52, 143.70, 159.50 ppm.

*3.5.8. Heptyl phenyl ketone (**7a**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.88$ (t, $J = 4.20$ Hz, 3H), 1.28–1.39 (m, 8H), 1.73 (penta, $J = 4.50$ Hz, 2H), 2.95 (t, $J = 4.50$ Hz, 2H), 7.43–7.96 (m, 5H) ppm. ^{13}C-NMR: δ 13.98, 22.56, 24.35, 29.09, 29.29, 31.65, 38.56, 127.99, 128.48, 132.76, 137.13, 200.46 ppm.

*3.5.9. 1-Phenyl-1-octanol (**7b**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.89$ (t, $J = 6.90$ Hz, 3H), 1.27 (br s, 10H), 1.71–1.79 (m, 2H), 1.94 (s, 1H), 4.66 (dd, $J = 13.20$, 1.20 Hz, 1H), 7.26–7.36 (m, 5H) ppm. ^{13}C-NMR: δ 14.05, 22.61, 25.81, 29.18, 29.46, 31.78, 39.08, 74.67, 125.87, 127.43, 128.39, 144.93 ppm.

*3.5.10. Decyl phenyl ketone (**7c**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.88$ (t, $J = 6.00$ Hz, 3H), 1.26–1.34 (m, 14H), 1.73 (penta, $J = 7.20$ Hz, 2H), 2.95 (t, $J = 7.20$ Hz, 2H), 7.41–7.97 (m, 5H) ppm. ^{13}C-NMR: δ 14.00, 22.58, 24.27, 29.23, 29.29, 29.42, 29.49, 31.80, 38.49, 127.94, 128.42, 132.71, 136.99, 200.34 ppm.

*3.5.11. 10-Undecyl phenyl ketone (**7d**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.29$–1.44 (m, 12H), 1.74 (penta, $J = 7.20$ Hz, 2H), 2.04 (q, $J = 6.60$ Hz, 2H), 2.96 (t, $J = 7.20$ Hz, 2H), 4.91–5.03 (m, 2H), 5.77–5.86 (m. 1H), 7.43–7.98 (m, 5H) ppm. ^{13}C-

NMR: δ 24.32, 28.88, 29.07, 29.33, 29.40, 33.75, 38.57, 114.08, 128.01, 128.50, 132.85, 137.06, 139.17, 200.53 ppm.

*3.5.12. Cyclohexylmethyl phenyl ketone (**7e**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 0.99–1.31 (m, 5H), 1.64–1.79 (m, 5H), 1.98 (m, 1H), 2.82 (d, J = 6.60 Hz, 2H), 7.42–7.96 (m, 5H) ppm. ^{13}C-NMR: δ 26.07, 26.19, 33.35, 34.44, 46.10, 128.04, 128.43, 132.74, 137.42, 200.11 ppm.

*3.5.13. 4-Phenylbutyl phenyl ketone (**7f**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 1.75–1.83 (m, 4H), 2.74 (t, J = 7.80 Hz, 2H), 3.01 (t, J = 6.60 Hz, 2H), 7.21–7.99 (m, 10H) ppm. ^{13}C-NMR: δ 23.90, 31.02, 37.73, 38.31, 125.68, 127.96, 128.24, 128.34, 128.49, 132.84, 136.96, 142.17, 200.17 ppm.

*3.5.14. 1,5-Diphenyl-1-pentanol (**7g**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 1.33–1.89 (m, 6H), 2.07 (br s, 1H), 2.64 (t, J = 7.20 Hz, 2H), 4.67 (dd, J = 13.20, 1.20 Hz, 2H), 7.19–7.42 (m, 5H) ppm. ^{13}C-NMR: δ 25.46, 31.34, 35.78, 38.83, 74.46, 125.58, 125.81, 127.44, 128.20, 128.31, 128.37, 142.50, 144.79 ppm.

3.6. Typical preparation of benzylic manganese phosphates and their cross-coupling reactions

Benzyl diethyl phosphate (9 mmol) was added via a syringe to the slurry of highly active manganese (10 mmol) being stirred in THF (12 ml) at r.t. The slurry was stirred overnight at r.t. The reaction was monitored by TLC and/or GC. After the completion of the oxidative addition, the mixture was cooled to 0 °C using an ice bath. 1,2-Dibromoethane was added to the mixture at this temperature, and the mixture was stirred for 5 min. To the reaction mixture was added an appropriate electrophile (8 mmol) through a syringe. After being stirred for 1 h, the mixture was quenched with 2 M HCl solution and extracted with diethyl ether. The combined organic layers were washed with $NaHCO_3$, $Na_2S_2O_3$, and brine, dried over anhydrous $MgSO_4$, and concentrated using a rotary evaporator. Flash column chromatography (ethyl acetate/hexanes) afforded the corresponding product.

*3.6.1. 4-Chlorobenzyl phenyl ketone (**9a**)*

M.p.: 55–56 °C; IR(KBr) 1675 cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 4.24 (s, 2H), 7.10–7.75 (m, 7H), 7.93–8.13 (m, 2H) ppm. ^{13}C-NMR: δ 44.43, 128.49, 128.84, 129.48, 129.60, 131.22, 133.76, 133.92, 134.39, 137.54, 137.54, 196.55 ppm.

*3.6.2. 2-(3-Methoxyphenyl)-1-phenyl ethanone (**9b**)*

B.p. 140–143 °C (0.27 mmHg); IR(KBr) 1675 cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 3.73 (s, 3H), 4.03 (s, 2H), 6.66–6.93 (m, 3H), 7.09–7.64 (m, 4H), 7.90–8.11 (m, 2H) ppm. HRMS 226.0994, Calc. for $C_{15}H_{14}O_2$ 226.0994.

*3.6.3. 2-(4-Methylphenyl)-1-phenyl ethanone (**9c**)*

M.p.: 95–96 °C; IR(KBr) 1685 cm^{-1}(C=O). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 2.32 (s, 3H), 4.23 (s, 2H), 7.03–7.70 (m, 7H), 7.95–8.20 (m, 2H) ppm.

*3.6.4. 1-Phenyl-2-(2-pyridinyl)-ethanone (**9d**)*

M.p.: 52–54 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 4.50 (s, 2H), 6.06 (s, enolic –CH=), 6.92–8.60 (m, 10H) ppm. EIMS m/z (relative intensity) 197 [M$^+$, 15], 169 (30), 168 (36), 120 (8), 105 (100), 92 (12), 77 (68).

*3.6.5. 4-Chlorobenzyl pentadecyl ketone (**9e**)*

White solid; m.p.: 56–58 °C; IR(KBr) 1680 cm^{-1} (C=O). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 0.9 (t, 3H), 1.25 (m. 26H), 2.48 (t, 2H), 3.69 (s, 2H), 7.12–7.36 (m, 4H) ppm. ^{13}C-NMR: δ 14.05, 23.95, 29.88, 30.03, 32.51, 40.73, 46.63, 129.70, 130.35, 132.23, 132.47, 207.12 ppm.

*3.6.6. 4-Fluoro-α-phenyl benzeneethanol (**10a**)*

M.p.: 45 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 1.82 (br s, 1H), 2.99(d, J = 6.90 Hz, 2H), 4.86 (t, J = 6.90 Hz, 1H), 6.92–7.01 (m, 2H), 7.08–7.16 (m, 2H), 7.26–7.38 (m, 5H) ppm. ^{13}C-NMR: δ 45.01, 75.33, 115.22, 125.91, 127.67, 128.34, 130.80, 133.66, 143.61, 161.45. HRMS 216.2440, Found: 216.2444 ppm.

*3.6.7. 4-Fluoro-α-phenyl benzeneethanol (**10b**)*

M.p.: 43–45 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): δ = 2.07 (br s, 1H), 2.29(s, 3H), 2.90 (d, J = 6.11 Hz, 2H), 4.78 (t, J = 6.10 Hz, 1H), 7.02 (s, 4H), 7.26 (s, 5H) ppm. EIMS m/z (relative intensity) 77 (33), 79 (41), 91 (26), 103 (5), 104 (3), 105 (19), 106 (100), 107 (39).

3.7. Homo-coupling reactions of functionalized benzyl halide

The slurry of active manganese (2 mmol) in 15 ml of THF was added to benzyl halides (3.8 mmol) and the reaction mixture was stirred at r.t. The reaction progress was monitored by Gas chromatography. After being stirred for 10 min, the reaction mixture was quenched with saturated ammonium chloride aqueous solution and the organic layer was extracted with diethyl ether (2 × 10 ml). The combined organic layers were washed with saturated sodium thiosulfate aqueous solution (10 ml) and dried over anhydrous magnesium sulfate and concentrate using rotary evaporator. Flash column chromatography (hexane/ethyl acetate) or recrystallization afforded the corresponding bibenzyls.

*3.7.1. 1,2-bis(4-Cyanophenyl)ethane (**11a**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.00$ (s, 4H), 7.21–7.58 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 37.15$, 110.25, 118.80, 129.20, 132.26, 146.03 ppm.

*3.7.2. 1,2-bis(3-Cyanophenyl)ethane (**11b**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.97$ (s, 4H), 7.33–7.53 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 36.77$, 112.51, 118.72, 129.23, 130.10, 131.88, 132.97, 141.85 ppm.

*3.7.3. 1,2-bis(2-Cyanophenyl)ethane (**11c**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.17$ (s, 4H), 7.29–7.34 (m, 4H), 7.47–7.53 (m, 2H), 7.59–7.62 (m, 2H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 36.12, 112.83, 118.32, 127.61, 130.37, 133.33

*3.7.4. 2,3-Diphenylbutane (**11d**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.03$–1.06 (m, 6H), 2.80–2.84 (m, 2H), 7.23–7.37 (m, 10H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 21.02$, 47.23, 126.03, 127.60, 128.27, 146.48 ppm.

*3.7.5. 1,2-bis(4-Carbomethoxyphenyl)ethane (**11e**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.97$ (s, 4H), 3.89 (s, 6H), 7.18 (d, $J = 8.11$ Hz, 4H), 7.93 (d, $J = 8.11$ Hz, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 37.94, 52.55, 128.65, 129.09, 130.28, 147.07, 167.57 ppm.

*3.7.6. 1,2-bis(4-Nitrophenyl)ethane (**11f**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.09$ (s, 4H), 7.29 (d, $J = 8.82$ Hz, 4H), 8.14 (d, $J = 8.82$ Hz, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 37.59$, 124.46, 129.96, 147.33, 148.75 ppm.

*3.7.7. 1,2-bis(4-Bromophenyl)ethane (**11g**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.77$ (s, 4H), 6.97–7.02 (m, 4H), 7.37–7.42 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 37.91$, 120.52, 131.67, 132.15, 140.80 ppm.

*3.7.8. 1,2-bis(4-Chlorophenyl)ethane (**11h**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.85$ (s, 4H, SiMe3), 7.06–7.19 (m, 4H), 7.22–7.28 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 37.89$, 129.22, 130.65, 132.48, 140.46 ppm.

*3.7.9. 1,2-bis(2,6-Dichlorophenyl)ethane (**11i**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.26$ (s, 4H), 7.05–7.14 (m, 2H), 7.23–7.34 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 30.20$, 128.78, 128.98, 136.89, 137.48 ppm.

*3.7.10. 1,2-bis(3,5-Dimethoxyphenyl)ethane (**11j**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.86$ (s, 4H), 3.80 (s, 12H), 6.31–6.39 (m, 6H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 38.48$, 56.01, 98.61, 107.33, 144.55, 147.68, 161.92 ppm.

*3.7.11. 1,2-bis(2-Methylphenyl)ethane (**11k**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.34$ (s, 6H), 2.86 (s, 4H), 7.10–7.23 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 20.08$, 34.55, 126.75, 129.88, 131.10, 137.23, 141.50 ppm.

3.8. Typical preparation of functionalized benzylic manganese halides and their cross-coupling reactions with aryl iodides under palladium catalyst

Benzyl halide (1.8 mmol) in THF (10 ml) was added via cannula to a slurry of active manganese (2 mmol) being stirred in THF (10 ml) at r.t. The reaction mixture was stirred at r.t. for 20 min. The reaction progress was monitored by Gas chromatography. After the completion of the oxidative addition, the mixture was cooled to 0 °C using ice-bath. 1,2-Dibromoethane was added to the mixture via syringe and the mixture was allowed to stir for 5 min. The resulting mixture was added via a cannula to a mixture of aryl iodides (1.2 mmol) and 5 mol.% of $Pd(PPh_3)_4$ catalyst in THF (10 ml). The mixture was stirred at r.t. for 2 h. An saturated aqueous solution of ammonium chloride (10 ml) was added then the mixture was extracted with diethyl ether (2 × 10 ml). The combined organic layers were washed with saturated aqueous solution of sodium thiosulfate (10 ml), then dried over magnesium sulfate. Removal of solvents and flash column chromatography (hexane/ethyl acetate) afforded diarylmethane.

*3.8.1. Ethyl 4-benzylbenzoate (**12a**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.42$ (t, $J =$ 7.15 Hz, 3H), 4.06 (s, 2H), 4.41 (q, $J = 7.15$ Hz, 2H), 7.20–8.05 (m, 9H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.22$, 41.77, 60.68, 126.25, 128.34, 128.49, 128.79, 128.82, 129.68, 140.06, 146.27, 166.42 ppm. HRMS Calc. for $C_{16}H_{16}O_2$ 240.1150, Found: 240.1151.

*3.8.2. Ethyl 4-(4′-bromobenzyl)benzoate (**12b**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.39$ (t, $J =$ 7.15 Hz, 3H), 3.98 (s, 2H), 4.37 (q, $J = 7.15$ Hz, 2H), 7.03–8.00 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.27$, 41.18, 60.80, 120.19, 128.63, 128.78, 129.00, 129.81, 129.99, 130.58, 131.60, 139.10, 145.56, 166.39 ppm.

*3.8.3. 3-(3′,5′-Dimethoxybenzyl)benzonitrile (**12c**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 3.78$ (s, 6H), 3.94 (s, 2H), 6.32–6.38 (m, 3H), 7.36–7.51 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 42.14$, 55.87,

98.83, 107.74, 113.05, 119.54, 129.82, 130.58, 132.89, 133.98, 142.26, 144.71, 161.66 ppm.

*3.8.4. Ethyl 4-(4′-chlorobenzyl)benzoate (**12d**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.42$ (t, $J =$ 7.15 Hz, 3H), 4.05(s, 2H), 4.37 (q, $J = 7.15$ Hz, 2H), 7.09–8.01 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.47$, 41.88, 61.78, 129.66, 129.69, 130.76, 131.11, 133.01, 139.66, 146.56, 167.34 ppm.

*3.9. Typical procedure for the coupling reaction of **1f** with aldehydes and acid chlorides (**13a–13d**, **14–18**)*

The benzylic manganese reagent was prepared as before. To the resulting benzylic reagents was added the aldehydes (or acid chloride) at r.t. After being stirred for 1 h, the mixture was quenched with 2 M HCl solution and extracted with diethyl ether. The combined organic layers were washed with saturated aqueous solution of sodium thiosulfate (10 ml), then dried over magnesium sulfate. Removal of solvents and flash column chromatography (hexane/ethyl acetate) afforded the corresponding coupling product.

*3.9.1. 1-(3,5-Dimethoxyphenyl)-2-hydroxytridecane (**13a**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.88$ (t, $J =$ 5.96 Hz, 3H), 1.26–1.52 (m, 20H), 1.60 (br s, 1H), 2.54, 2.58 (dd, $J = 8.59$ Hz, 8.58 Hz, 1H), 2.75, 2.80 (dd, $J =$ 3.81 Hz, 3.82 Hz, 1H), 3.78 (s, 7H), 6.35–6.37 (m, 3H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.09$, 22.66, 25.75, 29.33, 29.61, 29.64, 31.89, 36.84, 44.36, 55.24, 72.48, 98.38, 107.30, 140.99, 160.89 ppm.

*3.9.2. 1-(3,5-Dimethoxyphenyl)-2-hydroxypentadecane (**13b**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.89$ (t, $J =$ 6.20 Hz, 3H), 1.26–1.53 (m, 24H), 1.62 (s, 1H), 2.54, 2.59 (dd, $J = 8.58$ Hz, 8.82 Hz, 1H), 2.75, 2.80 (dd, $J =$ 4.06 Hz, 4.05 Hz, 1H), 3.78 (s, 7H), 6.35–6.38 (m, 3H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.08$, 25.74, 29.33, 29.64, 31.89, 36.84, 44.36, 55.21, 72.47, 98.36, 107.28, 140.98, 160.87 ppm.

*3.9.3. 1-(3,5-Dimethoxyphenyl)-pentadecan-2-one (**13c**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.88$ (t, $J =$ 6.90 Hz, 3H), 1.23–1.25 (m, 20H), 1.53 (br s, 2H), 2.44 (t, $J = 7.39$ Hz, 2H), 3.60 (s, 2H), 3.78 (br s, 6H), 6.35 (br s, 3H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 14.06$, 22.65, 23.70, 29.05, 29.32, 29.42, 29.59, 31.88, 41.76, 50.42, 55.25, 98.93, 107.28, 136.49, 160.93, 208.46 ppm.

*3.9.4. 1-(3,5-Dimethoxyphenyl)-heptadecan-2-one (**13d**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 0.88$ (t, $J =$ 5.72 Hz, 3H), 1.23–1.25 (m, 24H), 1.59 (br s, 2H), 2.43 (t, $J = 7.39$ Hz, 2H), 3.59 (s, 2H), 3.78 (s, 6H), 6.35 (br s, 3H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 14.08, 22.65, 23.70, 29.07, 29.32, 29.42, 29.55, 29.61, 29.64, 31.88, 41.76, 50.42, 55.25, 98.93, 107.37, 136.49, 160.91, 208.45 ppm.

*3.9.5. 2-(3,5-Dimethoxyphenyl)-1-phenylethan-1-ol (**14**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.09$ (br s, 1H), 2.88–3.03 (m, 2H), 3.76 (s, 6H), 4.88, 4.91 (dd, $J =$ 4.76 Hz, 4.77 Hz, 1H), 6.36 (br s, 3H), 7.26–7.28 (m, 5H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta =$ 46.40, 55.21, 55.24, 75.03, 98.67, 107.36, 125.87, 127.57, 128.75, 140.25, 143.70, 160.80 ppm.

*3.9.6. 2-(3,5-Dimethoxyphenyl)-1-(3′-methoxyphenyl)ethan-1-ol (**15**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.35$ (br s, 1H), 2.91–2.96 (m, 2H), 3.75, 3.80 (ss, 9H), 4.83, 4.86 (dd, $J = 4.77$ Hz, 5.01 Hz, 1H), 6.36 (br s, 3H), 6.81–7.29 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 46.20$, 55.08, 74.81, 98.52, 107.27, 111.14, 112.99, 118.10, 129.25, 140.22, 145.43, 159.52, 160.62 ppm.

*3.9.7. 2-(3,5-Dimethoxyphenyl)-1-(4′-methoxyphenyl)ethan-1-ol (**16**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.17$ (br s, 1H), 2.91–2.94 (m, 2H), 3.75, 3.80 (ss, 9H), 4.83 (t, $J =$ 7.39 Hz, 1H), 6.35 (br s, 3H), 6.81, 7.27 (dd, $J = 11.45$ Hz, 8.58 Hz, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 46.27$, 55.15, 74.62, 98.54, 107.31, 113.66, 128.08, 135.91, 140.41, 158.95, 160.70 ppm.

*3.9.8. 1-(3,4-Dimethoxyphenyl)-2-(3′,5′-dimethoxyphenyl)ethan-1-ol (**17**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.16$ (br s, 1H), 2.90–2.94 (m, 2H), 3.73, 3.86 (ss, 12H), 4.81, 4.83 (dd, $J = 5.40$ Hz, 5.49 Hz, 1H), 6.34 (br s, 3H), 6.80–6.90 (m, 3H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 46.33$, 55.15, 55.75, 55.82, 74.81, 98.52, 107.73, 108.94, 110.79, 118.04, 136.39, 140.32, 148.31, 148.85, 160.73 ppm.

*3.9.9. 1-(4-Benzyloxy-3-methoxyphenyl)-2-(3′,5′-dimethoxyphenyl)ethan-1-ol (**18**)*

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 2.45$ (br s, 1H), 2.92 (d, $J = 6.44$ Hz, 2H), 3.72, 3.86 (ss, 9H), 4.79 (t, $J = 6.68$ Hz, 1H), 5.14 (s, 2H), 6.35 (br s, 3H), 6.78–7.46 (m, 8H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 46.08$, 54.96, 55.69, 70.72, 74.61, 98.33, 107.21, 109.42, 113.50, 117.88, 127.03, 127.57, 128.27, 136.92, 140.25, 147.18, 149.33, 160.49 ppm.

3.10. Typical procedure for addtion reactions of benzyl manganese reagents to N-ethoxy-carbonylpyridinium salts (**19a–19c**)

To the slurry of activated manganese in THF (20 ml) was added a solution of BnBr (13 mmol) at r.t. After stirring under argon atmosphere for 1 h, this solution was added to a preformed solution of pyridinium chloride (from ethyl chloroformate (10 mmol), pyridine (10 mmol), THF (40 ml), at −30 °C for 30 min) at −30 °C. The mixture was warmed up slowly to r.t. and was allowed to stand overnight (10 h). Additional CH_2Cl_2 (20–30 ml) was added to the mixture, and the whole was washed with water and dried Na_2SO_4. After the solvent was evaporated, the residue was chromatographed on silica gel.

3.10.1. 4-Benzyl-N-ethoxycarbonyl-1,4-dihydropyridine (**19a**)

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.34$ (t, $J =$ 7.15 Hz, 3H), 2.76 (d, $J = 7.00$ Hz, 2H), 3.20–3.31 (m, 1H), 4.24 (q, $J = 7.15$ Hz, 2H), 4.58–4.96 (m, 2H), 6.90 (d, $J = 8.01$ Hz, 2H), 7.14–7.39 (m, 5H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 13.33$, 34.96, 41.07, 60.68, 110.71, 111.22, 122.45, 121.88, 126.25, 128.34, 129.18, 139.06, 149.57 ppm. IR (neat) 1730 cm^{-1}; EIMS *m/e* (relative intensity) 347, 345 [M^+, 2, 2], 260, 258, 256, 254 [$M^+ - 91$, 4, 31, 99, 100].

3.10.2. 4-(4′-Chlorobenzyl)-N-ethoxycarbonyl-1,4-dihydropyridine (**19b**)

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.33$ (t, $J =$ 7.15 Hz, 3H), 2.77 (d, $J = 7.00$ Hz, 2H), 3.20–3.33 (m, 1H), 4.24 (q, $J = 7.15$ Hz, 2H), 4.58–4.96 (m, 2H), 6.91 (d, $J = 8.01$ Hz, 2H), 7.14–7.39 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 13.33$, 34.96, 41.07, 60.68, 110.71, 111.22, 122.45, 121.88, 128.49, 129.48, 139.05, 149.57 ppm.

3.10.3. 4-(3′-Methoxybenzyl)-N-ethoxycarbonyl-1,4-dihydropyridine (**19c**)

^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 1.38$ (t, $J =$ 7.19 Hz, 3H), 2.767 (d, $J = 7.01$ Hz, 2H), 3.20–3.33 (m, 1H), 3.73 (s, 3H), 4.22 (q, $J = 7.15$ Hz, 2H), 4.60–4.96 (m, 2H), 6.90 (d, $J = 8.01$ Hz, 2H), 7.11–7.39 (m, 4H) ppm. ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): $\delta = 13.35$, 34.90, 40.21, 59.08, 60.48, 109.71, 110.22, 113.36, 113.89, 121.55, 125.45, 125.87, 129.45, 141.28, 148.57, 161.96 ppm.

4. Conclusion

A facile synthetic route to benzylic manganese reagents has been developed. The starting benzylic halide can contain a wide variety of substituents, and more importantly, benzyl alcohols can be used to make benzylic manganese reagents via direct oxidative addition of Mn* to benzyl sulfonates and phosphates. The reactions of the resulting benzylic manganese reagents proceed with good to excellent yields with several electrophiles in the absence of any catalyst and in some cases without any solvent. It has been found that this approach can be also used for the preparation of resorcinolic lipid derivatives, and bibenzyl lipid derivatives as well as substituted 1,4-dihydropyridines, and/or 4-benzylpyridines.

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