Palladium-Catalyzed Synthesis of Aryl Ketones from Boronic Acids and Carboxylic Acids Activated in situ by Pivalic Anhydride

Lukas J. Gooßen*[a] and Keya Ghosh[a]

Keywords: Aryl ketones / Boronic acids / Carboxylic acids / Catalysis / Palladium

A new palladium-catalyzed cross-coupling reaction between arylboronic acids and mixed anhydrides, generated in situ from carboxylic acids and pivalic anhydride, is presented. Optimization of the new catalyst and the reaction conditions led to the development of a convenient one-pot ketone synthesis directly from carboxylic and boronic acids in the presence of different (phosphane)palladium complexes in wet THF at 60 °C. Systematic studies were performed to elucidate the reaction mechanism of this transformation. The scope and the limitations of the new process are demonstrated by the synthesis of 33 functionalized ketones.

Introduction

The conversion of carboxylic acid derivatives into aryl ketones is a standard transformation often employed in the synthesis of complex organic molecules.[1] Most common are Friedel−Crafts acylations of arenes.[2] However, due to the limited regioselectivity, the products of this reaction are usually obtained as hard-to-separate isomeric mixtures. Furthermore, the reaction conditions tend to be incompatible with certain functional groups.

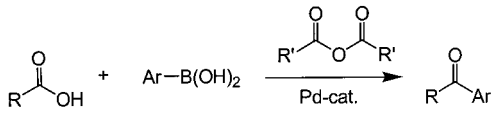
Alternatively, a variety of arylmetal species can be acylated with a wide range of carboxylic acid derivatives leading to single regioisomers of the desired aryl ketones.[3−5] The reaction of Weinreb amides with Grignard reagents is probably one of the most popular examples for this kind of transformation. Highly reactive acid chlorides can be treated with mild organometallic compounds, for example, organotin, -zinc, -copper, -boron, or -cadmium reagents, whereas less reactive acid derivatives such as anhydrides, nitriles, amides, or thioesters require more aggressive carbon nucleophiles, usually Grignard or organolithium compounds.

More recently, palladium-catalyzed cross-coupling reactions between acid chlorides[6] or thioesters[7] and boronic acids have been disclosed. However, although the low reactivities of the thioesters and the boronic acids result in an excellent functional group tolerance in the latter process, a stoichiometric amount of expensive copper thiophene carboxylate is used and the syntheses of the thioesters require additional reaction steps. Nevertheless, due to their good availability, low toxicity and excellent shelf life, boronic acids are certainly very attractive carbon nucleophiles for this type of transformation.[8]

Few procedures that allow the highly desirable direct conversion of carboxylic acids into ketones have been reported. All of them require the use of particularly reactive carbon nucleophiles under rather elaborate conditions in order to stop the reaction at the stage of the ketones and avoid the formation of tertiary alcohols.[4] An alternative, more practical ketone synthesis that would use the widely available substrate class of the carboxylic acids and tolerate most of the common functional groups is thus of great interest.

Recently, Yamamoto et al. have discovered a Pd-catalyzed reduction of carboxylic acids to aldehydes in the presence of pivalic anhydride.[9] We considered this to be a very promising strategy also for the arylation of carboxylic acids, if a catalyst could be found to efficiently catalyze the cross-coupling of carboxylic anhydrides with aryl metal species.

Thus, we were interested in finding a mild and general way of preparing aryl ketones by a palladium-catalyzed cross-coupling of boronic acids and carboxylic acids in the presence of an anhydride or a similar activating agent (Scheme 1).



Scheme 1. Ketone synthesis by cross-coupling of carboxylic and boronic acids

We first developed a catalytic system capable of coupling boronic acids with carboxylic anhydrides and then investigated on the generation of these carboxylic anhydrides from the corresponding acids. Using pivalic anhydride as an activating agent, we were finally able to combine the activation and cross-coupling step of the carboxylic with boronic

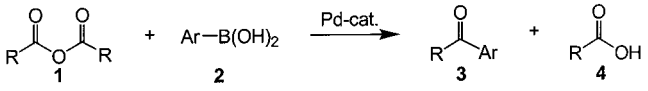
[a] Max-Planck-Institut für Kohlenforschung,
Kaiser-Wilhelm-Platz 1, 45470 Mülheim an der Ruhr, Germany
Fax: (internat.) + 49-(0)208/306-2985
E-mail: goossen@mpi-muelheim.mpg.de

acids into a convenient one-pot procedure. Some of our results have already been disclosed in a preliminary communication.[10,11] In this full paper, we report in detail on the experiments performed during the development of the one-pot procedure and discuss the crucial role played by water. Further investigations on the scope and limitations of the new ketone synthesis are also presented.

Results and Discussion

Aryl Ketones from Carboxylic Anhydrides

The key step in the development of a direct conversion of carboxylic acids was to find a catalytic system capable of coupling boronic acids with carboxylic anhydrides (Scheme 2).



Scheme 2. Palladium-catalyzed cross-coupling of carboxylic anhydrides with boronic acids

We chose the reaction of hexanoic anhydride (**1a**) and phenylboronic acid (**2a**) as our model system to screen several palladium catalysts under different conditions (Scheme 2, R = n-C_5H_{11}, Ar = Ph). Selected results are shown in Table 1. Our initial conditions were similar to those reported for the arylation of acid chlorides with boronic acids, but without the base in order to minimize the waste production.[6] Since the coupling proceeded much more slowly than reported for the acid chlorides, the temperature was raised to 60 °C (Entries 1, 2). In analogy to observations reported for acid chlorides, the presence of water in the reaction medium strongly facilitated the reaction turnover (Entries 2, 8). However, for the anhydrides, low yields were observed when the excess of water was too large (Entry 3). THF or DMF proved to be the most effective solvents, although other solvents could be used as well (Entries 2, 5−8).

Table 1. Coupling of anhydrides **1a**,**b** with phenylboronic acid (**2a**) [conditions: 1 mmol of anhydride, 1.2 mmol of phenylboronic acid, 0.03 mmol of $Pd(OAc)_2$, 0.07 mmol of ligand (0.035 mmol for chelating diphosphanes), 16 h, 60 °C; the yields were determined by GC]

Entry	R	Phosphane	Solvent	Water (mmol)	Yield (%)
1[a]	n-C_5H_{11}	PPh_3	THF	2.5	92
2	n-C_5H_{11}	PPh_3	THF	2.5	97
3	n-C_5H_{11}	PPh_3	THF	10	38
4	n-C_5H_{11}	PPh_3	DME	2.5	53
5	n-C_5H_{11}	PPh_3	DMF	2.5	92
6	n-C_5H_{11}	PPh_3	toluene	2.5	77
7	n-C_5H_{11}	PPh_3	CH_3CN	2.5	54
8	n-C_5H_{11}	PPh_3	THF	0	29
9	n-C_5H_{11}	−	THF	2.5	<3
10	n-C_5H_{11}	PCy_3	THF	2.5	91
11	n-C_5H_{11}	P(o-Tol)$_3$	THF	2.5	31
12	n-C_5H_{11}	BINAP	THF	2.5	<5
13	n-C_5H_{11}	P(p-$MeOC_6H_4$)$_3$	THF	2.5	97
14	n-C_5H_{11}	DPPF	THF	2.5	<5
15	n-C_5H_{11}	P(2-Fur)$_3$	THF	2.5	46
16	n-C_5H_{11}	P(tBu)$_3$	THF	2.5	28
17	Ph	PPh_3	THF	2.5	97
18	Ph	DPPF	THF	2.5	82
19	Ph	P(p-$MeOC_6H_4$)$_3$	THF	2.5	65
20	Ph	PCy_3	THF	2.5	70

[a] The reaction mixture was stirred for 36 h at 20 °C.

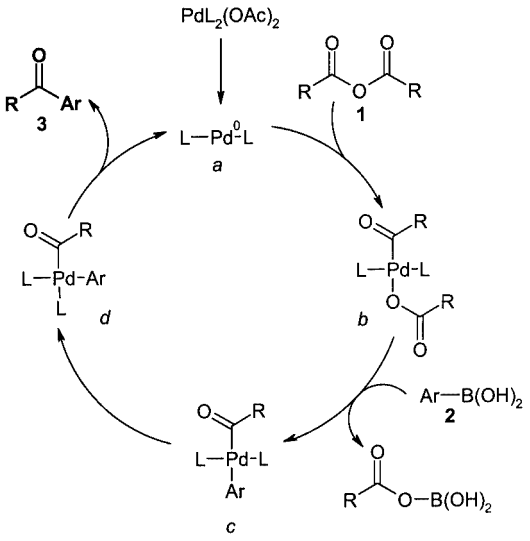
In contrast to the acylation with acid chlorides, no product was formed with carboxylic anhydrides in the absence of a ligand (Entry 9). For our model reaction, triphenylphosphane, as well as the more electron rich tris(o-methoxyphenyl)phosphane and tricyclohexylphosphane proved to be the most effective ligands. However, variation of the ligand for other substrates led us to conclude that there is no single ligand system that is optimal for all derivatives, although tris(o-methoxyphenyl)phosphane appears to be the most generally applicable ligand (see also Table 2). For best yields, the phosphane has to be chosen with respect to the reactivity of the anhydride and the acidity of the corresponding acid: For benzoic anhydride (**1b**), triphenylphosphane or DPPF are the most effective ligands (Entries 17−20), whereas for hexanoic anhydride (**1a**), tricyclohexylphosphane or tris(p-methoxyphenyl)phosphane are usually more suitable (Entries 10−16).

Table 2. Synthesis of aryl ketones **3a**−**n** according to Scheme 2 [conditions: 1 mmol of anhydride, 1.2 mmol of boronic acid, 0.03 mmol of $Pd(OAc)_2$, 0.07 mmol of P(p-MeOPh)$_3$, 2.5 mmol of water, 16 h, 60 °C; the yields are isolated yields]

No.	R	Ar	Yield (%)
3a	n-C_5H_{11}	Ph	96
3b[a]	Ph	Ph	96
3c	n-C_5H_{11}	p-MeO-phenyl	90
3d	n-C_5H_{11}	m-Cl-phenyl	97
3e[b]	n-C_5H_{11}	p-CH_3CO-phenyl	96
3f	n-C_5H_{11}	m-NO_2-phenyl	67
3g	n-C_5H_{11}	1-naphthyl	80
3h	n-C_5H_{11}	o-tolyl	96
3i	n-C_5H_{11}	2-furyl	84
3j	n-C_5H_{11}	3-thienyl	88
3k	$C(CH_3)=CH_2$	Ph	71
3l	n-$C_{11}H_{23}$	Ph	90
3m[a]	p-$MeOC_6H_4$	Ph	90
3n	tBu	Ph	trace

[a] 0.07 mmol of PCy_3 as ligand. [b] 0.07 mmol of PPh_3 as ligand.

A simplified reaction mechanism analogous to that of other palladium-catalyzed cross-coupling reactions can serve to explain some of these findings.[9,11,12] The symmetrical carboxylic anhydride **1** can be expected to add to a coordinatively unsaturated palladium(0) species *a* generating an acylpalladium(II) complex *b* (Scheme 3). After transmetalation of the carbon nucleophile **2** and isomerization to the *cis* isomer, the resulting (acyl)(aryl)palladium(II) complex *d* reductively eliminates the product ketone **3**, regenerating the palladium(0) species *a* and resuming the catalytic cycle.

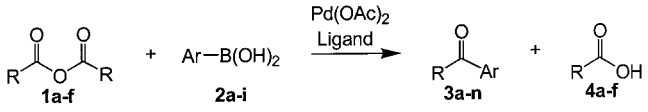


Scheme 3. Simplified catalytic cycle for symmetrical anhydrides

For the highly reactive acid chlorides, the oxidative addition obviously proceeds extremely well, so that even without phosphane ligands on the palladium atom, fast catalytic turnover in the arylation reactions is observed.[6] In the case of carboxylic anhydrides, however, the presence of phosphanes is required. The oxidative addition of organic substrates to palladium catalysts is known to be facilitated by electron-rich ligands. This is well documented especially for aryl halides, but the phenomenon is also known for carboxylic acid derivatives.[9,12] We monitored the reaction of a large excess of benzoic anhydride with $Pd(PPh_3)_4$ by NMR spectroscopy and detected no signals corresponding an acyl complex even at elevated temperatures. We thus assume that the oxidative addition of the anhydrides is not favoured and may well be the rate-determining step in the catalytic cycle. Yamamoto et al. come to the same conclusion.[11] The observation that the addition of water has a strong effect on the reaction suggests that the water accelerates the rate-determining step. In order to elucidate this effect, we performed a series of NMR experiments. THF solutions of $Pd(PPh_3)_4$ both in the absence and in the presence of water only show one sharp signal at $\delta = 25.4$ ppm in the ^{31}P NMR spectrum. The same signal is predominant in the ^{31}P NMR spectrum of a mixture of $Pd(PPh_3)_4$ with an excess of benzoic anhydride in dry THF. Upon addition of water, however, this sharp signal almost completely disappears and a broad signal at $\delta = 19.8$ ppm is detected. This suggests that in the presence of water, a rapid equilibration between several (phosphane)Pd complexes takes place. Although no signal could be clearly assigned to an (acyl)Pd species indicative of an oxidative addition, it appears likely that the benzoic anhydride is involved in this equilibrium.

The presence of electron-rich phosphanes should increase the reactivity of the palladium atom, and the less reactive the anhydride, the more electron-rich the ligands should be. This is in good coincidence with the experimental findings. A continuation of this trend is observed when carboxylic acid *N*-hydroxysuccinimidyl esters instead of carboxylic anhydrides are used as substrates in this cross-coupling: For such even less reactive acid derivatives, reaction turnover was observed exclusively with palladium catalysts bearing electron-rich tricyclohexylphosphane ligands.[13]

In principle, electron-rich ligands could be expected to give optimum results for all carboxylic anhydrides. However, we observed that palladium complexes with these ligands are not particularly stable under the reaction conditions. This can be explained by the higher basicity of electron-rich phosphanes that makes them more vulnerable towards protonation and oxidation, in particular when they are temporarily dissociated from the palladium atom. Thus, with electron-rich phosphanes, formation of palladium black and loss of catalytic activity occurred for some substrates before the reaction was complete. For these substrates, better yields are obtained with less active but more robust ligands (Table 1, Entries 17−20). Usually, the most electron-rich palladium-phosphane complex to remain stable under the reaction conditions led to the best yields for a given substrate. The broad scope of the optimized reaction protocol is demonstrated by the examples given in Table 2. The optimum ligand for each substrate combination in the reactions according to Scheme 4 is also indicated.



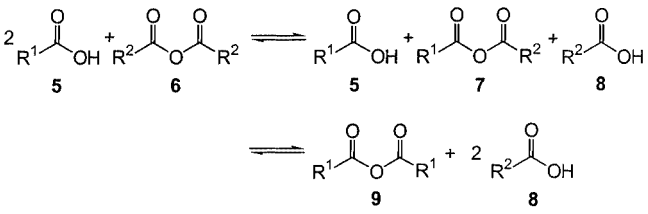
Scheme 4. Palladium-catalyzed cross-coupling of carboxylic anhydrides with boronic acids

As can be seen in Table 2, various symmetrical anhydrides were converted into the corresponding ketones in good yields. The reaction tolerates a variety of functional groups and works well with both electron-rich and electron-poor carboxylic anhydrides and boronic acids.

Even ketones **3g** and **3h** from sterically demanding boronic acids were smoothly formed, but the reaction was found to be very sensitive towards steric hindrance at the carboxylic anhydrides: with the bulky pivalic anhydride, almost no conversion of the starting material was observed and only traces of the desired product **3n** were formed.

Acitvation of Carboxylic Acids with Anhydrides

We next set out to identify a suitable method for generating mixed anhydrides from carboxylic acids under the conditions which had proved to be optimal for the Pd-catalyzed



Scheme 5. Equilibration between carboxylic acids and anhydrides

cross-coupling reaction. In order to find the optimum combination of reactants, we first investigated on the equilibrium reaction between various acids and anhydrides as shown in Scheme 5.

We monitored the reaction of various combinations of carboxylic acids **5** and anhydrides **6** in [D_8]THF (Scheme 4) by means of NMR spectroscopy. The relative amounts of the single components were calculated from the size of selected integrals in the ^{1}H spectra in comparison to an internal standard. The amount of hydrolyzed material was calculated by subtracting the total amount of all carboxylic anhydrides from the total amount of all anhydrides.

When combining benzoic acid (**5a**) with trifluoroacetic anhydride (**6a**), the corresponding mixed anhydride **7a** is formed exclusively and within seconds (Scheme 5, R^1 = Ph, R^2 = CF_3). The mixed anhydride, however, is completely hydrolyzed upon addition of 2 equiv. of water.

The progress of the reaction between equimolar amounts of benzoic acid (**5a**) and acetic anhydride (**6b**) (Scheme 5, R^1 = Ph, R^2 = CH_3) in [D_8]THF at room temperature in the presence of 2 equiv. of water is shown in (Figure 1, top). The presence of water had almost no influence on the equilibration as confirmed by a control experiment in dry THF. The reaction proceeds much more slowly than it does in the case of trifluoroacetic anhydride (**6a**) but still reasonably fast, leading to an equilibrium mixture of 54% acetic anhydride (**6b**), 40% mixed anhydride **7b** and 6% benzoic anhydride (**9b**). The hydrolysis was found to be comparatively slow: within 24 h less than 10% of the anhydrides had hydrolyzed in the presence of 2 equiv. of water.

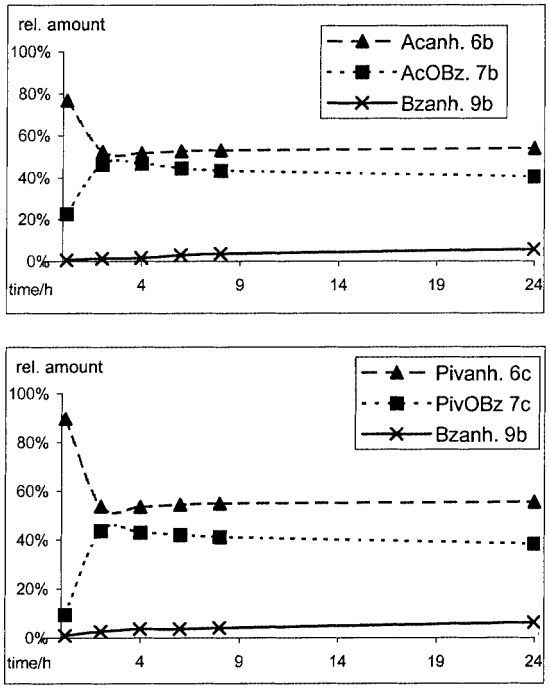


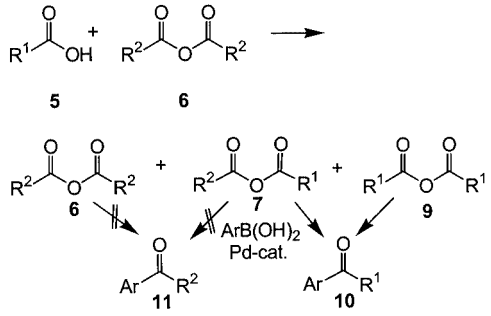
Figure 1. Equilibration between two different sets of carboxylic acids and anhydrides

The equilibration of benzoic acid and pivalic anhydride proceeded similarly fast and led to a mixture of 55% pivalic anhydride (**6c**), 38% mixed anhydride **7c**, and 6% of benzoic anhydride (**9b**). Again, the total amount of all hydrolyzed anhydrides was found to be below 10% after 24 h.

It was concluded that the activation of one carboxylic acid with another anhydride in situ under the conditions of the cross-coupling reaction is possible in principle.

In situ Activation and Cross-Coupling

In order to identify a method to exclusively generate one of the two possible ketones **10** and **11** out of such an equilibrium mixture of one carboxylic acid with another anhydride, we next investigated how the product distribution in the reaction displayed in Scheme 6 can be influenced.



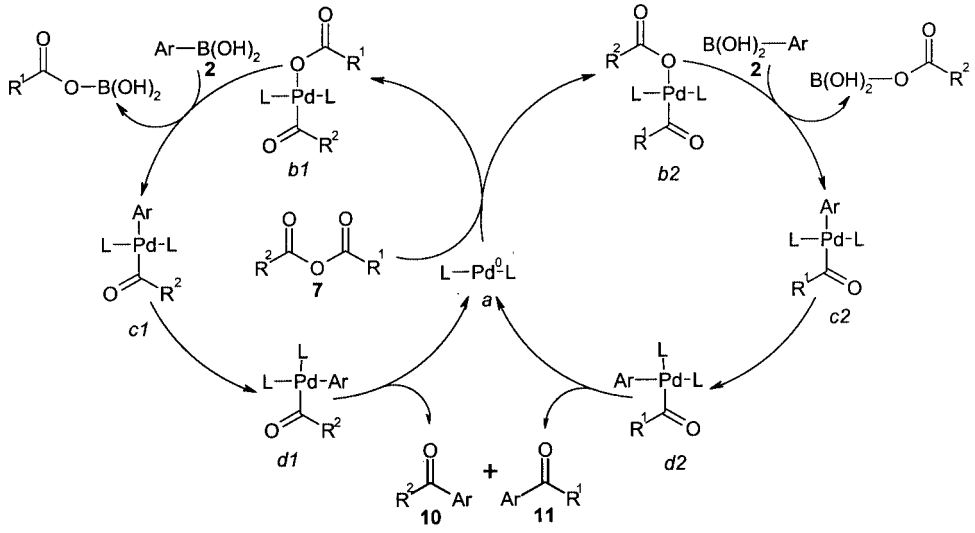
Scheme 6. Reaction of an equilibrium mixture of carboxylic anhydrides with a boronic acid

Several factors can be expected to determine the product distribution obtained upon treatment of an equilibrium mixture of the anhydrides **6**, **7**, and **9** with a boronic acid **2** in the presence of a palladium catalyst. Firstly, the two homoanhydrides **6** and **9** will react at different rates in the catalytic cycle shown in Scheme 3. Secondly, the mixed anhydride **7** should show some regioselectivity in the reaction with a palladium catalyst. The catalytic cycle for this reaction pathway is shown in Scheme 7.

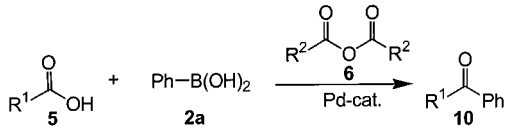
On oxidative addition of the mixed anhydride **7**, two different acylpalladium complexes *b1* and *b2* may form, leading to the two products **10** and **11** in otherwise identical catalytic cycles. Yamamoto's results and our NMR experiments suggest that the oxidative addition of the anhydrides is the rate-determining step in such a catalytic cycle.[11] If this is indeed the case, the ratio of the product ketones **10** and **11** should be determined by the selectivity of the formation of the two acyl complexes *b1* and *b2*.

One can then expect to see a significant influence of the electronic properties of the substituents R^1 and R^2 on the regiochemistry of the reaction similar to that observed for Friedel–Crafts acylations with mixed anhydrides.[14] If R^1 is more electron-rich than R^2, R^2 should be better at stabilizing the carboxylate leaving group and, therefore, ketone **11** should be the main product. On the other hand, steric factors should also influence the product distribution, since for symmetrical carboxylic anhydrides, a profound effect of the steric bulk of the anhydride substituents on the reaction rates had been observed (Table 2, compounds **3a**, **3n**).

The experimental results for the coupling reactions of mixtures of different acids and anhydrides with



Scheme 7. Simplified catalytic cycle for mixed anhydrides



Scheme 8. Coupling of a carboxylic acid with phenylboronic acid in the presence of an anhydride

phenylboronic acid according to Scheme 8 confirm these assumptions. As our initial in situ reaction conditions, we chose the optimum conditions determined for the cross-coupling of benzoic anhydride (R^2 = Ph) with phenylboronic acid (60 °C, wet THF, $Pd(OAc)_2/PPh_3$). The results are summarized in Table 3.

Table 3. Coupling of different sets of acids and anhydrides (see Scheme 8) [conditions: 1 mmol of R^1COOH, 1.5 mmol of $(R^2CO)_2O$, 1.2 mmol of phenylboronic acid, 0.03 mmol of $Pd(OAc)_2$, 0.07 mmol of Ph_3P, 2.5 mmol of water, 60 °C, 16 h; the yields were determined by GC]

Entry	R^1	R^2	$PhCOR^1$	$PhCOR^2$
1	CH_3	Ph	15	63
2	Ph	CH_3	70	11
3	*i*Bu	Ph	11	69
4	Ph	*i*Bu	47	12
5	CF_3	Ph	–	25
6	Ph	CF_3	<3	–
7	*t*Bu	Ph	<1	58
8	Ph	*t*Bu	70	<1
9	*t*Bu	CH_3	<1	46
10	CH_3	*t*Bu	85	<1

From the mixture of acetic acid with benzoic anhydride, acetophenone was obtained predominantly in the catalytic reaction with phenylboronic acid (Entry 1). A similar result was observed with the complementary mixture of benzoic acid and acetic anhydride (Entry 2). This result was expected for both reasons outlined above.

Both from a mixture of trifluoroacetic acid and benzoic anhydride and from the complementary mixture, only benzophenone was obtained, though in poor yields (Entries 5, 6). Apparently, the stability of the leaving group was decisive in this combination, overriding the steric factors. A reason for the low yields was decomposition of the catalyst under the extremely acidic conditions.

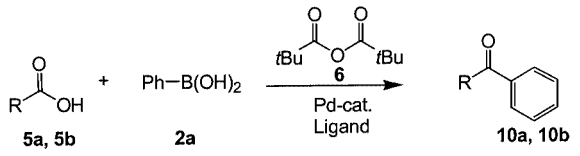
From a mixture of benzoic acid and pivalic anhydride, only benzophenone was formed, in excellent selectivity and satisfactory yield (Entries 7, 8). For this substrate combination, solely steric factors seemed to determine the regioselectivity, since from an electronic standpoint, benzoate would be the preferred leaving group within the mixed anhydride.

The pivalic anhydride also present in the mixture had previously proved to be unreactive towards cross-coupling (Table 2, compound **3n**), so that no *tert*-butyl ketone could have arisen from this homoanhydride. Benzoic anhydride, which is present in the reaction mixture in smaller quantities than the mixed anhydride, will also have contributed to the formation of benzophenone. In fact, benzoic anhydride should react more readily with the palladium atom than the mixed anhydride due to the higher stability of benzoate as the leaving group in comparison with pivalate, as discussed previously. Hence, although significantly larger quantities of the mixed anhydride **7** are present in the reaction mixture (Figure 1, bottom), the reaction pathway via the homoanhydride **9** should be faster and may become the main reaction pathway for electron-poor carboxylic acids.

Similar observations were made for the reaction of acetic acid and pivalic anhydride (Entries 9, 10). Hence, pivalic anhydride appears to be generally applicable as an activating agent for sterically less demanding carboxylic acids. Its low price in combination with the easy handling and high stability against water make pivalic anhydride particularly

practical. However, other sterically demanding anhydrides should also be suitable for this transformation.

In order to further optimize the reaction conditions for the new one-pot conversion, we chose the reaction of phenylpropionic acid (R = C_2H_4Ph) and pivalic anhydride **6** with phenylboronic acid (**2a**) as our model reaction and screened various palladium catalysts under different conditions (Scheme 9). The results are summarized in Table 4.



Scheme 9. Coupling of phenylpropionic and benzoic acid with phenylboronic acid

Overall, a trend very similar to that for the homoanhydrides can be observed. DME and THF proved to be the most effective solvents (Entries 2, 4−7). The optimum reaction temperature is 60 °C, but reasonable yields can be obtained even at lower temperatures (Entry 8). Again, different phosphanes give optimum yields for different substrates (Entries 2, 18). The great similarity of the observations made for the cross-coupling of the in situ mixtures and for the homoanhydrides supports our hypothesis that the reaction pathway via the homoanhydrides significantly contributes to the product formation.

In the one-pot procedure, the water content has an even more profound influence on the yields than in the case of the homoanhydrides (Entries 1−3). Without water, only sluggish turnover is observed. The reaction becomes much faster upon addition of a small quantity of water. In the presence of a larger excess, however, the yields start to drop again, presumably due to the competing hydrolysis of the anhydrides. In order to further elucidate the role of the water in the cross-coupling reaction of phenylpropionic acid/pivalic anhydride and phenylboronic acid, we performed an additional series of experiments in which water was substituted by other additives (Table 5).

Table 5. Influence of additives on the cross-coupling reactions [conditions: 1 mmol of phenylpropionic acid, 1.5 mmol of pivalic anhydride, 1.2 mmol of phenylboronic acid, 0.03 mmol of $Pd(OAc)_2$, 0.035 mmol of DPPF, 1 mmol of additive, 60 °C, 16 h; the yields were determined by GC]

Entry	Additive	Yield (%)[a]
1	H_2O[a]	90
2	MeOH[a]	<3
3	HOC_2H_4OH[a]	27
4	*p*-$TolSO_3H$	0
5	$ZnCl_2$	<3
6	LiBr	<3
7	KCN	10
8	K_2CO_3	92
9	KF	92

[a] 2.5 mmol of additive.

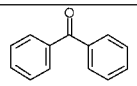
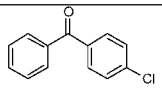
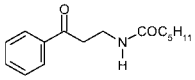
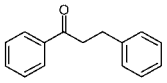
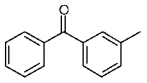
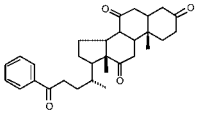
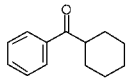
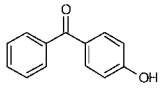
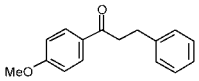
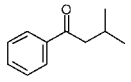
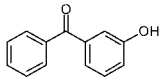
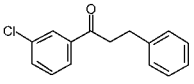
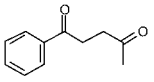
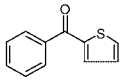
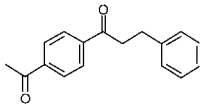
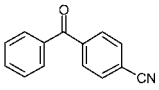
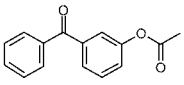
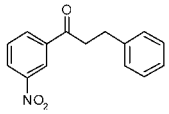
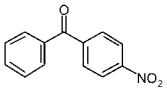
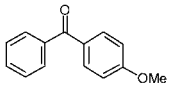
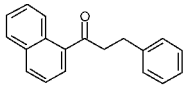
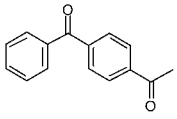
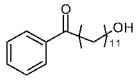
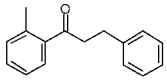
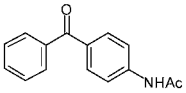
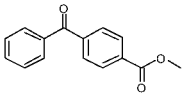
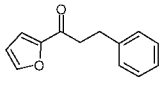
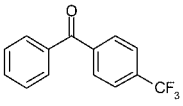
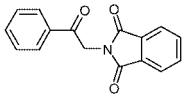
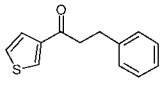
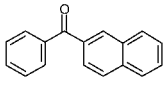
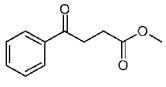
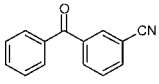
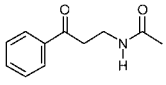
No significant acceleration of the reaction was observed when alcohols were added instead of water (Entry 2, 3). Even with ethylene glycol, which is known to strongly coordinate to boric acid, no significant yield enhancement was observed. The addition of acids led to a decrease in the yields and precipitation of the palladium was observed (Entry 4). In contrast to observations made for other palladium catalyses,[13−15] the addition of halides and

Table 4. Coupling of phenylpropionic and benzoic acid with phenylboronic acid [conditions: 1 mmol of acid, 1.5 mmol of pivalic anhydride, 1.2 mmol of phenylboronic acid, 0.03 mmol of $Pd(OAc)_2$, 0.07 mmol of ligand (0.035 mmol for chelating phosphanes), 60 °C, 16 h; the yields were determined by GC]

Entry	R	Phosphane	Solvent	H_2O (mmol)	Yield (%)
1	2-phenylethyl	PPh_3	THF	0	<1
2	2-phenylethyl	PPh_3	THF	2.5	91
3	2-phenylethyl	PPh_3	THF	10	74
4	2-phenylethyl	PPh_3	DME	2.5	84
5	2-phenylethyl	PPh_3	DMF	2.5	79
6	2-phenylethyl	PPh_3	toluene	2.5	62
7	2-phenylethyl	PPh_3	CH_3CN	2.5	18
8[a]	2-phenylethyl	PPh_3	THF	2.5	74
9	2-phenylethyl	PCy_3	THF	2.5	55
10	2-phenylethyl	P(*o*-Tol)$_3$	THF	2.5	76
11	2-phenylethyl	BINAP	THF	2.5	65
12	2-phenylethyl	P(*p*-$MeOC_6H_4$)$_3$	THF	2.5	79
13	2-phenylethyl	DPPF	THF	2.5	91
14	2-phenylethyl	P(2-Fur)$_3$	THF	2.5	46
15	2-phenylethyl	P(*t*Bu)$_3$	THF	2.5	28
16	2-phenylethyl	P(*p*-$CF_3C_6H_4$)$_3$	THF	2.5	33
17	Ph	PPh_3	THF	2.5	57
18	Ph	DPPF	THF	2.5	68
19	Ph	P(*p*-$MeOC_6H_4$)$_3$	THF	2.5	22
20	Ph	PCy_3	THF	2.5	50

[a] The reaction was performed at 20 °C.

Table 6. Synthesis of aryl ketones from carboxlic acids and arylboronic acids [conditions: 1 mmol of carboxylic acid, 1.2 mmol of boronic acid, 1.5 mmol of pivalic anhydride, 0.03 mmol of $Pd(OAc)_2$, 0.07 mmol of ligand (0.035 mmol for DPPF), 4 mL of solvent, 2.5 mmol of H_2O, 60 °C, 16 h; all yields given are isolated yields]

No.	Product[a]	Ligand[b]	Yield (%)	No.	Product[a]	Ligand[b]	Yield(%)	No.	Product[a]	Ligand[b]	Yield (%)
10a		C	68	**10m**		D	40	**10y**[d]		C	60
10b		C	83	**10n**		D	70	**10z**		A	81
10c[c]		A	60	**10o**		D	70	**12**		A	78
10d		A	90	**10p**		D	70	**13**		C	55
10e		A	65	**10q**		B	35	**14**		D	55
10f		B	80	**10r**		B	70	**15**		D	40
10g		C	75	**10s**		D	55	**16**		C	75
10h		D	54	**10t**		B	80	**17**		C	65
10i		B	85	**10u**		A	51	**18**		B	47
10j		D	40	**10v**[d]		B	45	**19**		A	72
10k		B	85	**10w**		A	70				
10l		D	40	**10x**[d]		C	80				

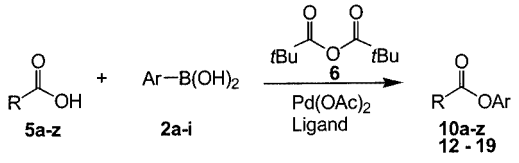
[a] Aryl groups originating from the boronic acids are placed on the left side of the oxo groups. [b] Ligands: A: P(*p*-$MeOC_6H_4)_3$; B: PPh_3; C: DPPF; D: PCy_3. [c] DME as solvent. [d] K_2CO_3 is used instead of H_2O.

pseudohalides did not facilitate the reaction either (Entries 5−7).

Only the addition of bases such as K_2CO_3 or KF instead of water further accelerated the reaction and the yields were even higher than under the standard conditions (Entries 8, 9). It is hard to rationalize these findings, if solely the oxidative addition is rate limiting, since it appears unlikely that these additives would accelerate this reaction step. However, the transmetallation step should be facilitated by these hard nucleophiles since they could coordinate to the boron atom

making it a better leaving group. This effect is well known for fluoride or carboxylates. However, it is surprising that water should be such an efficient nucleophile in this respect.[16] The effect of the water could, however, also arise from its ability to facilitate the dissociation of the carboxylic acids into the carboxylates and increase the mobility of these ions in solution. Thus, coordination of carboxylates to the boronic acids would be more likely to occur in a wet reaction medium, where the carboxylic acids are partially dissociated. Still, further investigations are clearly needed to fully understand the mechanism of this complex reaction.

After optimizing the reaction conditions, we went on to investigate the scope of the new reaction. The results are summarized in Table 6. For the reasons mentioned before, different phosphanes were chosen for different substrates. The optimal phosphane for each carboxylic acid is indicated in the table. Phenylpropionic acid works similarly well with all four phosphanes, but, for this derivative, different phosphanes were observed to give optimal yields of the ketones **12**−**19** depending on the boronic acid employed (Scheme 10).



Scheme 10. Coupling of carboxylic acid with boronic acids in the presence of pivalic anhydride

The results shown in Table 6 demonstrate the generality of the new transformation. Both electron-rich and electron-poor carboxylic acids can be treated with a variety of boronic acids, and most functional groups such as halo, keto, cyano, ester, nitro, or protected amino groups were successfully converted. The heterocyclic ketones **10q**, **18**, and **19** were also generated in reasonable yields.

Most notably, even carboxylic acids containing aliphatic or aromatic hydroxy groups were smoothly converted and only very small amounts of esters were formed as side products in the synthesis of ketones **10o**, **10p**, and **10t**. In the absence of a base, carboxylic anhydrides are obviously not very reactive acylating agents for hydroxy groups.

Due to the acidic conditions, the cross-coupling is, however, not suitable for acid-sensitive compounds. Thus, we did not observe any product formation with hydroxybutyric acid. Instead, elimination of water led to the formation of α,β-unsaturated carbonyl compounds. For such sensitive substrates, we recommend using our alternative reaction protocol, were the carboxylic acids are activated with disuccinimidyl carbonate under neutral conditions.[13]

Whereas protected β-amino acids readily reacted to the corresponding amino ketones **10x** and **10y**, with α-amino acids, fast hydrolysis of these particularly acidic mixed anhydrides was observed under standard conditions and only a low yield (22%) of the amino ketone **10v** was obtained. Since we had previously observed that the addition of a base may further increases the yields of the cross-coupling reaction (Table 6), we added some K_2CO_3, but no water. Under these conditions, significantly higher yields of the amino ketones could be isolated. However, this reaction variant is no longer salt-free.

Conclusion

Overall, the newly discovered palladium-catalyzed cross-coupling reaction represents a one-step, high-yielding synthesis of aryl ketones directly from the plethora of available carboxylic acids and boronic acids. The reaction is very generally applicable to a wide range of substrates and most functional groups are tolerated. The reaction requires only commercially available, nontoxic chemicals, does not call for strictly anhydrous conditions, and produces only a minimum amount of waste: Besides boric acid, only pivalic acid is formed as side product and several methods are known to regenerate the anhydride from this carboxylic acid.[16] The new transformation may thus become a valuable alternative to the standard procedures both for industrial use and for applications in drug discovery or combinatorial chemistry.

Experimental Section

General Methods: All reagents were obtained from commercial sources and used without further purification. The solvents were dried and degassed using standard procedures. NMR spectra were recorded with Bruker AC 200, DPX 300, or AMX 400 instruments. ^{1}H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ with TMS as the internal standard. The in situ ^{1}H NMR experiments were recorded at 400 MHz in [D_8]THF using a Bruker AMX 400 instrument. The mass spectra were measured with a MAT 95 (70 eV) instrument. Column chromatography was performed on silica gel (230−400 mesh; Kieselgel 60 "Merck") or on basic aluminium oxide (0.05−0.15 mm; 5016A "Merck").

General Procedure for the Conversion of Carboxylic Anhydrides into Aryl Ketones. 1-Phenylhexan-1-one (3a): Palladium acetate (6.70 mg, 0.03 mmol) and tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol), were placed in a 20-mL reaction vessel. Subsequently, phenylboronic acid (**2a**) (146 mg, 1.20 mmol) in THF (2 mL), hexanoic anhydride (**1a**) (214 mg, 1.00 mmol), and water (2.50 mmol) were added, and the reaction mixture was purged with argon. The reaction mixture was stirred for 16 h at 60° C while the progress of the reaction was monitored by gas chromatography. After the reaction was complete, the volatiles were removed in vacuo. The residue was taken up in a minimum amount of dichloromethane, applied to the top of a 10-cm column of basic alumina and eluted using a hexane/ethyl acetate gradient. The first fraction contained mainly biphenyl formed during the reduction of the Pd^{II} precatalyst. The second fraction, eluted with 4% ethyl acetate/hexane, contained pure **3a** (167 mg, 95%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.90 (t, *J* = 7.0 Hz, 3 H), 1.25−1.43 (m, 4 H), 1.66−1.81 (m, 2 H), 2.94 (t, *J* = 7.0 Hz, 2 H), 7.39−7.48 (m, 3 H), 7.95 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.9, 22.5, 24.0, 31.5, 38.5, 128.0, 128.4, 132.7, 137.0, 200.4 ppm. MS (EI): *m*/*z* (%) = 176 (25) [M^+], 154 (1), 133 (10), 120 (60), 105 (100)

ppm. HRMS (EI): calcd. for $C_{12}H_{16}O$ [M^+]: 176.120115; found 176.120023.

Diphenylmethanone (3b): The ketone was obtained according to the general procedure from benzoic anhydride (**1b**) (226 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3b** (174 mg, 96%) as a white solid. The spectroscopic data are identical with those reported in literature.

(4-Methoxyphenyl)hexan-1-one (3c): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and (4-methoxyphenyl)boronic acid (**2b**) (182 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3c** (187 mg, 91%) as a white solid. The spectroscopic data are identical with those reported in literature.

1-(3-Chlorophenyl)hexan-1-one (3d): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and (3-chlorophenyl)boronic acid (**2c**) (187 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3d** (203 mg, 97%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (m, 3 H), 1.38 (m, 4 H), 2.91 (m, 2 H), 7.32−7.51 (m, 2 H), 7.79 (m, 1 H), 7.89 (m, 3 H), ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.5, 22.1, 23.4, 31.0, 38.2, 125.7, 127.7, 129.5, 132.3, 134.5, 138.2, 198.6 ppm. MS (EI): *m*/*z* (%) = 210 (20) [M^+], 192 (1), 167 (13), 154 (98), 139 (100). HRMS (EI): calcd. for $C_{12}H_{15}ClO$ [M^+]: 210.081143; found 210.081174. $C_{12}H_{15}ClO$ (210.0): calcd. C 68.41, H 7.18; found C 68.40, H 7.11.

1-(4-Acetylphenyl)hexan-1-one (3e): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and (4-acetylphenyl)boronic acid (**2d**) (196 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 20:80) afforded compound **3c** (210 mg, 96%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (m, 3 H), 1.24−1.49 (m, 4 H), 1.70−1.82 (m, 2 H), 2.56 (s, 3 H), 2.90 (m, 2 H), 8.12 (s, 4 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.5, 22.5, 23.8, 26.8, 31.4, 38.9, 128.2, 128.4, 140.0, 140.2, 197.4, 199.9 ppm. MS (EI): *m*/*z* (%) = 218 (21) [M^+], 203 (3), 175 (5), 162 (35), 147 (100) ppm. HRMS (EI): calcd. for $C_{14}H_{18}O_2$ [M^+]: 218.130679; found 218.130707. $C_{14}H_{18}O_2$ (218.1): calcd. C 77.03, H 8.31; found C 77.05, H 8.15.

1-(3-Nitrophenyl)hexan-1-one (3f): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and (3-nitrophenyl)boronic acid (**2e**) (200 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 30:70) afforded compound **3f** (148 mg, 67%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (m, 3 H), 1.34−1.49 (m, 4 H), 1.72−1.79 (m, 2 H), 3.01 (m, 2 H), 7.68 (m, 1 H), 8.26 (m, 1 H), 8.40 (m, 1 H), 8.77 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 22.4, 23.7, 31.3, 38.8, 122.9, 127.2, 129.8, 133.5, 138.3, 148.4, 198.2 ppm. MS (EI): *m*/*z* (%) = 221 (4) [M^+], 204 (7), 178 (3), 165 (100), 150 (60). HRMS (EI): calcd. for $C_{12}H_{15}NO_3$ [M^+]: 221.105193; found 221.105117. $C_{12}H_{15}NO_3$ (221.2): calcd. C 65.14, H 6.83; found C 65.09, H 6.75.

1-(Naphthalen-1-yl)hexan-1-one (3g): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and 1-naphthylboronic acid (**2f**) (206 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 5:95) afforded compound **3g** (180 mg, 80%) as white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (m, 3 H), 1.32−1.40 (m, 4 H), 1.75−1.80 (m, 2 H), 3.00 (m, 2 H), 7.42−7.55 (m, 3 H), 8.53 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ =13.9, 22.7, 24.4, 31.3, 42.2, 123.9, 124.6, 125.7, 126.3, 127.1, 128.3, 129.5, 130.1, 132.2, 136.4, 205.0 ppm. MS (EI): *m*/*z* (%) = 226 (24) [M^+], 208 (1), 183 (3), 170 (30), 155 (100), 127 (60). HRMS (EI): calcd. for $C_{16}H_{18}O$ [M^+]: 226.135765; found 226.135660.

1-(*o*-Tolyl)hexan-1-one (3h): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and (2-methylphenyl)boronic acid (**2g**) (163 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3h** (186 mg, 98%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (m, 3 H), 1.30−1.38 (m, 4 H), 1.63−1.74 (m, 2 H), 2.49 (s, 3 H), 2.88 (m, 2 H), 7.21−7.39 (m, 3 H), 7.59 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.7, 21.0, 22.1, 23.2, 32.5, 42.2, 124.4, 125.6, 131.8, 132.1, 138.4, 138.7, 204.2 ppm. MS (EI): *m*/*z* (%) = 190 (7) [M^+], 175 (5), 161 (1), 134 (12), 119 (100), 105 (2). HRMS (EI): calcd. for $C_{13}H_{18}O$ [M^+]: 190.135765; found 190.135675.

1-(Furan-2-yl)hexan-1-one (3i): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and 2-furanylboronic acid (**2h**) (134 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 5:95) afforded compound **3i** (139 mg, 84%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (t, *J* = 7.0 Hz, 3 H), 1.34−1.49 (m, 4 H), 1.72−1.79 (m, 2 H), 3.01 (t, *J* = 7.0 Hz, 2 H), 7.66 (m, 1 H), 8.36−8.42 (m, 1 H), 8.75 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.7, 22.4, 23.9, 31.4, 38.5, 113.6, 116.1, 146.4, 156.7, 185.2 ppm. MS (EI): *m*/*z* (%) = 166 (1) [M^+], 138 (1), 123 (13), 110 (100), 95 (60). HRMS (EI): calcd. for $C_{10}H_{14}O_2$ [M^+]: 166.099379; found 166.099409.

1-(Thiophen-3-yl)hexan-1-one (3j): The ketone was obtained according to the general procedure from hexanoic anhydride (**1a**) (214 mg, 1.00 mmol) and 3-thiophenylboronic acid (**2i**) (153 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 5:95) afforded compound **3f** (160 mg, 88%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90 (m, 3 H), 1.32−1.38 (m, 4 H), 1.70−1.76 (m, 2 H), 2.86 (m, 2 H), 7.29 (m, 1 H), 7.53 (m, 1 H), 8.04 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 22.5, 24.1, 31.5, 39.9, 126.1, 127.1, 131.6, 142.5, 194.9 ppm. MS (EI): *m*/*z* (%) = 182 (14) [M^+], 166 (1), 139 (7), 126 (60), 111 (100). HRMS (EI): calcd. for $C_{10}H_{14}OS$ [M^+]: 182.076537; found 182.076514.

2-Methyl-1-phenylpropenone (3k): The ketone was obtained according to the general procedure from methacrylic anhydride (**1c**) (154 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 5:95) afforded compound **3k** (103 mg, 71%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.07 (m, 3 H), 5.61 (m, 1 H), 5.89 (s, 1 H), 7.39−7.54 (m, 3 H), 7.73 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 18.6, 127.0,

128.1, 129.0, 131.6, 137.7, 143.7, 198.3 ppm. MS (EI): *m*/*z* (%) = 1 46 (40) [M$^+$], 131 (1), 118 (12), 105 (100), 77 (50). HRMS (EI): calcd. for $C_{10}H_{10}O$ [M$^+$]: 146.073165; found 146.073135.

1-Phenyldodecan-1-one (3l): The ketone was obtained according to the general procedure from lauric anhydride (**1d**) (382 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3l** (235 mg, 90%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 7.0 Hz, 3 H), 1.25−1.39 (m, 16 H), 1.68−1.78 (m, 2 H), 2.95 (t, *J* = 7.0 Hz, 2 H), 7.42−7.58 (m, 3 H), 7.95 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.1, 22.6, 24.4, 29.3, 29.4, 29.5, 29.6, 31.9, 38.6, 128.0, 128.5, 132.8, 137.1, 200.6 ppm. MS (EI): *m*/*z* (%) = 260 (20) [M$^+$], 227 (1), 177 (1), 133 (12), 120 (100), 105 (70). HRMS (EI): calcd. for $C_{18}H_{28}O$ [M$^+$]: 260.214015; found 260.214155.

(4-Methoxyphenyl)(phenyl)methanone (3m): The ketone was obtained according to the general procedure from *p*-anisic anhydride (**1e**) (286 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **3m** (190 mg, 90%) as a white solid. The spectroscopic data are identical with those reported in literature.

General Procedure for the Conversion of Carboxylic Acids into Aryl Ketones. Diphenylmethanone (10a): Palladium acetate (6.70 mg, 0.03 mmol), diphenyl(ferrocenyl)phosphane (DPPF) (19.4 mg, 0.04 mmol), and benzoic acid (**5a**) (122 mg, 1.00 mmol) were placed in a 20-mL reaction vessel. Subsequently, THF (4 mL) pivalic anhydride (279 mg, 1.50 mmol), water (45.0 mg, 2.50 mmol), and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) in THF (2 mL) were added, and the reaction mixture was purged with argon. The reaction mixture was stirred 16 h at 60 °C, while the progress of the reaction was monitored by gas chromatography. After the reaction was complete, the volatiles were removed in vacuo. The residue was taken up in a minimum amount of dichloromethane, applied to the top of a 10-cm column of basic alumina, and eluted using a hexane/ethyl acetate gradient. The first fraction contained mainly biphenyl formed during the reduction of the Pd^{II} precatalyst. The second fraction, eluted by 10% ethyl acetate/hexane, contained almost pure product. After removal of the volatiles and crystallization of the residue from hexane, compound **10a** (123 mg, 68%) was obtained as a white solid. The spectroscopic data are identical with those of **3b**.

1,3-Diphenylpropan-1-one (10b): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using DPPF (19.4 mg, 0.04 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **10b** (173 mg, 83%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.13 (t, *J* = 6.0 Hz, 2 H), 3.32 (t, *J* = 6.0 Hz, 2 H), 7.19−7.61 (m, 8 H), 7.95 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 29.8, 40.1, 125.8, 127.7, 128.1, 128.2, 128.3, 132.7, 136.5, 141.0, 198.8 ppm. MS (EI): *m*/*z* (%) = 210 (53) [M$^+$], 192 (1), 181 (1), 105 (100), 77 (46), 51 (17). HRMS (EI): calcd. for $C_{15}H_{14}O$ [M$^+$]: 210.104465; found 210.104474. $C_{15}H_{14}O$ (210.3): calcd. C 85.68, H 6.71; found C 85.37, H 6.66.

Cyclohexyl(phenyl)methanone (10c): The ketone was obtained according to the general procedure from cyclohexanecarboxylic acid (**5c**) (128 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 5:95) afforded the compound **10c** (113 mg, 60%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.90−2.12 (m, 10 H), 3.28 (m, 1 H), 7.30−7.63 (m, 3 H), 7.93 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 25.6, 26.0, 29.0, 45.2, 127.8, 128.2, 132.3, 136.0, 203.4 ppm. MS (EI): *m*/*z* (%) = 188 (33) [M$^+$], 170 (1), 147 (2), 133 (15), 120 (11), 105 (100). HRMS (EI): calcd. for $C_{13}H_{16}O$ [M$^+$]: 188.120115; found 188.120151.

3-Methyl-1-phenylbutan-1-one (10d): The ketone was obtained according to the general procedure from isovaleric acid (**5d**) (186 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **10d** (145 mg, 90%) as a colorless oil. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.99 (d, *J* = 7.0 Hz, 6 H), 2.29 (m, 1 H), 2.82 (d, *J* = 7.0 Hz, 2 H), 7.48−7.52 (m, 3 H), 7.95 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 22.7, 25.1, 47.4, 128.0, 128.5, 132.8, 137.5, 199.8 ppm. MS (EI): *m*/*z* (%) = 162 (22) [M$^+$], 147 (10), 120 (30), 105 (100), 77 (42), 51 (20). HRMS (EI): calcd. for $C_{11}H_{14}O$[M$^+$]: 162.104465; found 162.104576.

1-Phenylpentan-1,4-dione (10e): The ketone was obtained according to the general procedure from 4-oxopentanoic acid (**5e**) (106 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 20:80) afforded compound **10e** (114 mg, 65%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.25 (s, 3 H), 2.88 (t, *J* = 6.3 Hz, 2 H), 3.28 (t, *J* = 6.3 Hz, 2 H), 7.46−7.51(m, 3 H), 7.98 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 30.0, 32.3, 37.0, 128.0, 128.5, 133.1, 136.6, 198.4, 207.2 ppm. MS (EI): *m*/*z* (%) = 176 (12) [M$^+$], 161 (22), 133 (10), 105 (100), 77 (45). HRMS (EI): calcd. For $C_{11}H_{12}O_2$ [M$^+$]: 176.083729; found 176.083636.

4-Benzoylbenzonitrile (10f): The ketone was obtained according to the general procedure from 4-cyanobenzoic acid (**5f**) (147 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 40:60) afforded compound **10f** (165 mg, 80%) as a white solid. The spectroscopic data are identical with those reported in literature.

(4-Nitrophenyl)(phenyl)methanone (10g): The ketone was obtained according to the general procedure from 4-nitrobenzoic acid (**5g**) (167 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using DPPF (19.4 mg, 0.04 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 50:50) afforded compound **10g** (170 mg, 75%) as a white solid. The spectroscopic data are identical with those reported in literature.

1-(4-Benzoylphenyl)ethanone (10h): The ketone was obtained according to the general procedure from 4-acetylbenzoic acid (**5h**) (164 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 20:80) afforded compound **10h** (120 mg, 54%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.67 (s, 3 H), 7.45−7.63 (m, 3 H), 7.77−7.82 (m, 4 H), 8.05 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ =26.8, 128.1, 128.4, 129.0, 129.2, 132.9, 136.8, 139.5, 141.3, 195.9, 197.4 ppm. MS (EI): *m*/*z* (%) = 224 (75) [M$^+$], 209 (100), 181 (10), 147 (30), 105 (70). HRMS (EI): calcd. for $C_{15}H_{12}O_2$ [M$^+$]: 224.083729; found 224.083666.

***N*-(4-Benzoylphenyl)acetamide (10i):** The ketone was obtained according to the general procedure from 4-(acetamido)benzoic acid

(**5i**) (179 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 60:40) afforded compound **10i** (203 mg, 85%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 2.21 (s, 3 H), 7.46−7.89 (m, 9 H), 8.19 (s, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 24.3, 118.8, 128.3, 129.8, 131.5, 132.3, 132.8, 137.7, 142.1, 169.0, 195.4 ppm. MS (EI): *m*/*z* (%) = 239 (67) [M^+], 197 (55), 162 (10), 141 (10), 120 (100), 105 (12), 92 (12). HRMS (EI): calcd. for $C_{15}H_{13}NO_2$ [M^+]: 239.094628; found 239.094689.

(Phenyl)[4-(trifluoromethyl)phenyl]methanone (10j): The ketone was obtained according to the general procedure from 4-(trifluoromethyl)benzoic acid (**5j**) (190 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **10j** (100 mg, 40%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 7.46−7.90 (m, 9 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 125.3, 128.4, 130.0, 133.3, 136.7, 140.7, 195.4 ppm. MS (EI): *m*/*z* (%) = 250 (58) [M^+], 231 (10), 201 (1), 181 (2), 173 (28), 145 (30), 105 (100). HRMS (EI): calcd. for $C_{14}H_9F_3O$ [M^+]: 250.060549; found 250.060594.

(Naphthalen-2-yl)(phenyl)methanone (10k): The ketone was obtained according to the general procedure from 2-naphthoic acid (**5k**) (172 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **10k** (197 mg, 85%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 7.66−7.47 (m, 5 H), 7.85−7.96 (m, 6 H), 8.27 (s, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 125.7, 126.7, 127.8, 128.3, 129.3, 130.0, 131.8, 132.2, 132.3, 134.8, 137.9, 196.7 ppm. MS (EI): *m*/*z* (%) = 232 (100) [M^+], 202 (10), 155 (75), 127 (60), 105 (30), 77 (28). HRMS (EI): calcd. for $C_{17}H_{12}O$ [M^+]: 232.088815; found 232.088958.

3-Benzoylbenzonitrile (10l): The ketone was obtained according to the general procedure from 3-cyanobenzoic acid (**5l**) (147 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 40:60) afforded compound **10l** (82 mg, 40%) as a white solid. The spectroscopic data are identical with those reported in literature.

(4-Chlorophenyl)(phenyl)methanone (10m): The ketone was obtained according to the general procedure from 4-chlorobenzoic acid (**5m**) (156 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **10m** (86 mg, 40%) as a white solid. The spectroscopic data are identical with those reported in literature.

(Phenyl)(*m*-tolyl)methanone (10n): The ketone was obtained according to the general procedure from 3-methylbenzoic acid (**5n**) (136 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 5:95) afforded compound **10n** (137 mg, 70%) as a colorless oil. ^1H NMR (200 MHz, $CDCl_3$): δ = 2.42 (s, 3 H), 7.31−7.63 (m, 7 H), 7.80 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 20.9, 127.3, 128.0, 128.2, 130.0, 130.3, 132.2, 133.1, 137.6, 137.7, 138.0, 196.5 ppm. MS (EI): *m*/*z* (%) = 196 (82) [M^+], 181 (20), 119 (100), 105 (65), 91 (45). HRMS (EI): calcd. for $C_{14}H_{12}O$ [M^+]: 196.088815; found 196.088747.

(4-Hydroxyphenyl)(phenyl)methanone (10o): The ketone was obtained according to the general procedure from 4-hydroxybenzoic acid (**5o**) (138 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10o** (138 mg, 70%) as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ = 6.72 (brs, 1 H), 6.91 (m, 2 H), 7.43 (m, 2 H), 7.54 (m, 1 H), 7.76 (m, 4 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 115.3, 128.4, 129.2, 129.8, 132.1, 133.0, 138.0, 161.2, 197.3 ppm. MS (EI): *m*/*z* (%) = 198 (45) [M^+], 181 (2), 169 (2), 141 (6), 121 (100), 105 (25). HRMS (EI): calcd. for $C_{13}H_{10}O_2$ [M^+]: 198.068079; found 198.068117.

(3-Hydroxyphenyl)(phenyl)methanone (10p): The ketone was obtained according to the general procedure from 3-hydroxybenzoic acid (**5p**) (138 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10p** (138 mg, 70%) as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.10 (m, 1 H), 7.24−7.47 (m, 5 H), 7.54 (m, 1 H), 7.77 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 116.6, 120.0, 122.6, 128.2, 129.4, 130.1, 132.6, 137.3, 138.7, 156.2, 197.3 ppm. MS (EI): *m*/*z* (%) = 198 (100) [M^+], 181 (6), 170 (4), 141 (4), 121 (70), 105 (90). HRMS (EI): calcd. for $C_{13}H_{10}O_2$ [M^+]: 198.068079; found 198.068194.

(Phenyl)(thiophen-3-yl)methanone (10q): The ketone was obtained according to the general procedure from 2-thiophenylcarboxylic acid (**5q**) (128 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 20:80) afforded compound **10q** (66 mg, 35%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 7.15 (m, 1 H), 7.48−7.71(m, 5 H), 7.85 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 127.9, 128.3, 129.0, 132.2, 134.1, 134.7, 138.1, 143.5, 187.9 ppm. MS (EI): *m*/*z* (%) = 188 (82) [M^+], 171 (10), 160 (10), 111 (100), 105 (45), 77 (45). HRMS (EI): calcd. for $C_{11}H_8OS$ [M^+]: 188.029587; found 188.029549.

3-Benzoylphenyl Acetate (10r): The ketone was obtained according to the general procedure from 3-acetoxybenzoic acid (**5r**) (180 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 20:80) afforded compound **10r** (168 mg, 70%) as a colorless oil. ^1H NMR (300 MHz, $CDCl_3$): δ = 2.31 (s, 3 H), 7.29−7.68 (m, 7 H), 7.79(m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 20.7, 122.8, 125.3, 127.1, 128.0, 129.0, 129.6, 132.2, 136.8, 138.5, 150.1, 168.8, 195.1 ppm. MS (EI): *m*/*z* (%) = 240 (30) [M^+], 198 (100), 181 (5), 141 (10), 121 (45). HRMS (EI): calcd. for $C_{15}H_{12}O_3$ [M^+]: 240.078644; found 240.078806. $C_{15}H_{12}O_3$ (240.3): calcd. C 74.99, H 5.03; found C 74.84, H 4.98.

(4-Methoxyphenyl)(phenyl)methanone (10s): The ketone was obtained according to the general procedure from 4-methoxybenzoic acid (**5s**) (152 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **10s** (116 mg, 55%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.87 (s, 3 H), 6.96 (m, 2 H), 7.41−7.56 (m, 3 H), 7.73−7.85 (m, 4 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.4, 113.5, 128.1, 129.6, 130.1, 131.8, 132.5, 138.2, 163.2, 195.5 ppm. MS (EI): *m*/*z*

(%) = 212 (40) [M$^+$], 135 (100), 105 (12), 92 (10), 77 (30). HRMS (EI): calcd. for $C_{14}H_{12}O_2$ [M$^+$]: 212.083729; found 212.083698.

12-Hydroxy-1-phenyldodecan-1-one (10t): The ketone was obtained according to the general procedure from 12-hydroxydodecanoic acid (**5t**) (216 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10t** (220 mg, 80%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.27−1.74 (m, 19 H), 2.94 (m, 2 H), 3.62 (m, 2 H), 7.41−7.53 (m, 3 H), 7.97 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 24.3, 25.7, 29.3, 29.4, 29.5, 32.8, 38.6, 63.1, 128.0, 128.5, 132.8, 137.1, 200.6 ppm. MS (EI): *m*/*z* (%) = 276 (14) [M$^+$], 258 (1), 246 (1), 215 (1), 133 (12), 120 (100). HRMS (EI): calcd. for $C_{18}H_{28}O_2$ [M$^+$]: 276.208929; found 276.208987. $C_{18}H_{28}O_2$ (276.4): calcd. C 78.21, H 10.21; found C 78.13, H 10.16.

Methyl 4-Benzoylbenzoate (10u): The ketone was obtained according to the general procedure from 4-(methoxycarbonyl)benzoic acid (**5u**) (180 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 10:90) afforded compound **10u** (122 mg, 51%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.96 (s, 3 H), 7.45−7.62 (m, 3 H), 7.76−7.80 (m, 4 H), 8.13 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.4, 128.4, 128.7, 129.4, 129.7, 132.9, 133.2, 136.9, 141.3, 166.2, 196.0 ppm. MS (EI): *m*/*z* (%) = 240 (52) [M$^+$], 209 (22), 181 (20), 163 (52), 105 (100). HRMS (EI): calcd. for $C_{15}H_{12}O_3$ [M$^+$]: 240.078644; found 240.078585.

2-(2-Oxo-2-phenylethyl)isoindole-1,3-dione (10v): The ketone was obtained according to the general procedure from *N*-phthaloylglycine (**5v**) (205 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10v** (119 mg, 45%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.13 (s, 2 H), 7.52−7.64 (m, 3 H), 7.75 (m, 2 H), 7.91 (m, 2 H), 8.03 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 44.2, 123.5, 128.1, 132.2, 134.0, 134.1, 134.4, 167.9, 190.9 ppm. MS (EI): *m*/*z* (%) = 265 (18) [M$^+$], 237 (1), 208 (1), 180 (1), 160 (20), 133 (5), 105 (100). HRMS (EI): calcd. for $C_{16}H_{11}NO_3$ [M$^+$]: 265.073893; found 265.073997.

Methyl 4-Oxo-4-phenylbutyrate (10w): The ketone was obtained according to the general procedure from monomethyl succinate (**5w**) (132 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 20:80) afforded compound **10w** (134 mg, 70%) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.75 (t, *J* = 7.0 Hz, 2 H), 3.30 (t, *J* = 7.0 Hz, 2 H), 3.70 (s, 3 H), 7.42−7.58 (m, 3 H), 7.97 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.0, 33.3, 51.8, 128.0, 128.6, 133.2, 136.5, 173.3, 198.0 ppm. MS (EI): *m*/*z* (%) = 192 (20) [M$^+$], 174 (1), 161 (22), 133 (2), 105 (100). HRMS (EI): calcd. for $C_{11}H_{12}O_3$ [M$^+$]: 192.078644; found 192.078476.

***N*-(3-Oxo-3-phenylpropyl)acetamide (10x):** The ketone was obtained according to the general procedure from *N*-acetyl-β-alanine (**5x**) (131 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using DPPF (19.4 mg, 0.035 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10x** (152 mg, 80%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.92 (s, 3 H), 3.23 (m, 2 H), 3.68 (m, 2 H), 6.17 (brs, 1 H), 7.42−7.59 (m, 3 H), 7.93 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 23.3, 34.2, 38.2, 128.0, 128.7, 133.5, 136.4, 170.1, 199.6 ppm. MS (EI): *m*/*z* (%) = 191 (24) [M$^+$], 176 (1), 148 (13), 132 (12), 120 (12), 105 (100). HRMS (EI): calcd. for $C_{11}H_{13}O_2N$ [M$^+$]: 191.094628; found 191.094493.

***N*-(3-Oxo-3-phenylpropyl)hexanamide (10y):** The ketone was obtained according to the general procedure from *N*-hexanoyl-β-alanine (**5y**) (187 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using DPPF (19.4 mg, 0.035 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 60:40) afforded compound **10y** (150 mg, 60%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.82 (t, *J* = 6.0 Hz, 3 H), 1.13−1.25 (m, 4 H), 1.55−1.59 (m, 2 H), 2.14 (m, 2 H), 3.22 (m, 2 H), 3.68 (m, 2 H), 6.17 (brs, 1 H), 7.42−7.58 (m, 3 H), 7.91 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.8, 22.3, 25.3, 31.4, 34.1, 36.8, 38.2, 128.0, 128.7, 133.5, 136.4, 173.6, 199.6 ppm. MS (EI): *m*/*z* (%) = 247 (22) [M$^+$], 218 (3), 204 (8), 191 (52), 148 (28), 105 (100). HRMS (EI): calcd. for $C_{15}H_{21}O_2N$ [M$^+$]: 247.157228; found 247.157320.

9a,11a-Dimethyl-1-(1-methyl-4-oxo-4-phenylbutyl)-3a,3b,5,5a,6,8,9,9a,9b,10,11a-dodecahydrocyclopenta[*a*]phenanthrene-4,7,11-trione (10z): The ketone was obtained according to the general procedure from dehydrocholic acid (**5b**) (402 mg, 1.00 mmol) and phenylboronic acid (**2a**) (146 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 40:60) afforded compound **10z** (374 mg, 81%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90−2.35 (m, 29 H), 2.86−2.95 (m, 4 H), 7.27−7.58 (m, 3 H), 7.93 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 11.8, 18.9, 21.9, 25.1, 27.6, 29.6, 29.7, 35.2, 36.0, 36.4, 38.6, 42.7, 44.9, 45.5, 45.6, 46.8, 48.9, 51.7, 56.9, 128.0, 128.5, 132.9, 137.0, 200.7, 208.6, 209.0, 212.0 ppm. MS (EI): *m*/*z* (%) = 462 (15) [M$^+$], 444 (30), 384 (8), 343 (38), 329 (48), 120 (100). HRMS (EI): calcd. for $C_{30}H_{38}O_4$ [M$^+$]: 462.277008; found 462.277101. $C_{30}H_{38}O_4$ (462.6): calcd. C 77.89, H 8.22; found C 78.07, H 8.34.

1-(4-Methoxyphenyl)-3-phenylpropan-1-one (12): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and (4-methoxyphenyl)boronic acid (**2b**) (182 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **12** (187 mg, 78%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.06 (t, *J* = 7.0 Hz, 2 H), 3.24 (t, *J* = 7.0 Hz, 2 H), 3.85 (s, 3 H), 6.92 (m, 2 H), 7.23−7.19 (m, 5 H), 7.95 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.3, 40.1, 55.5, 113.7, 126.1, 128.4, 128.5, 129.9, 130.3, 141.5, 163.5, 197.8 ppm. MS (EI): *m*/*z* (%) = 240 (33) [M$^+$], 135 (100), 121 (2), 107 (6), 92 (8), 77 (13). HRMS (EI): calcd. for $C_{16}H_{16}O_2$ [M$^+$]: 240.115029; found 240.115054. $C_{16}H_{16}O_2$ (240.3): calcd. C 79.97, H 6.71; found C 80.12, H 6.78.

1-(3-Chlorophenyl)-3-phenylpropan-1-one (13): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and (3-chlorophenyl)boronic acid (**2c**) (187 mg, 1.20 mmol) using DPPF (19.4 mg, 0.035 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 10:90) afforded compound **13** (134 mg, 55%) as a white solid. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.94 (m, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 29.9, 40.5, 126.2, 128.1, 128.3, 128.5, 129.9, 132.9, 134.9, 138.3, 140.9, 197.8 ppm. MS (EI): *m*/*z* (%) = 244 (52) [M$^+$], 209 (22), 191 (1), 165 (1), 139 (100). HRMS

(EI): calcd. for $C_{15}H_{13}ClO$ [M^+]: 244.065493; found 244.065566. $C_{15}H_{13}ClO$ (244.0): calcd. C 73.62, H 5.35; found C 73.55, H 5.36.

1-(4-Acetylphenyl)-3-phenylpropan-1-one (14): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and (4-acetylphenyl)boronic acid (**2d**) (196 mg, 1.00 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **14** (138 mg, 55%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 2.63 (s, 3 H), 3.07 (t, *J* = 7.0 Hz, 2 H), 3.33 (t, *J* = 7.0 Hz, 2 H), 7.22−7.31 (m, 5 H), 8.01 (s, 4 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 26.8, 29.9, 40.7, 126.2, 128.1,128.3, 128.4, 128.5, 139.7, 140.1, 140.9, 197.4, 198.5 ppm. MS (EI): *m*/*z* (%) = 252 (86) [M^+], 237 (2), 209 (18), 191 (1) 178 (1), 147 (100). HRMS (EI): calcd. for $C_{17}H_{16}O_2$ [M^+]: 252.115029; found 252.115133. $C_{17}H_{16}O_2$ (252.3): calcd. C 80.93, H 6.39; found C 80.98, H 6.34.

1-(3-Nitrophenyl)-3-phenylpropan-1-one (15): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and (3-nitrophenyl)boronic acid (**2e**) (200 mg, 1.20 mmol) using tricyclohexylphosphane (19.6 mg, 0.07 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 20:80) afforded compound **19** (102 mg, 40%) as a white solid. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.10 (t, *J* = 7.0 Hz, 2 H), 3.37 (t, *J* = 7.0 Hz, 2 H), 7.35−7.17 (m, 5 H), 7.66 (m, 1 H), 8.31 (m, 1 H), 8.41 (m, 1 H), 8.75 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 29.8, 40.6, 122.9, 126.3, 127.3, 128.3, 128.6, 129.8, 133.5, 138.0, 140.5, 148.4, 196.8 ppm. MS (EI): *m*/*z* (%) = 255 (93) [M^+], 238 (32), 208 (10), 150 (90), 105 (100). HRMS (EI): calcd. for $C_{15}H_{13}NO_3$ [M^+]: 255.089543; found 255.089225.

1-(Naphthalen-1-yl)-3-phenylpropan-1-one (16): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and 1-naphthylboronic acid (**2f**) (206 mg, 1.20 mmol) using DPPF (19.4 mg, 0.035 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 15:85) afforded compound **16** (195 mg, 75%) as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.17 (t, *J* = 7.0 Hz, 2 H), 3.40 (t, *J* = 7.0 Hz, 2 H), 7.22−7.60 (m, 8 H), 7.81−8.01 (m, 3 H), 8.64 (m, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 30.6, 43.8, 124.3, 125.8, 126.2, 126.4, 127.4, 127.9, 128.4, 128.5, 130.1, 132.6, 134.0, 135.9, 141.1, 203.4 ppm. MS (EI): *m*/*z* (%) = 260 (42) [M^+], 242 (2), 202 (1), 169 (10), 155 (100), 127 (55). HRMS (EI): calcd. for $C_{19}H_{16}O$ [M^+]: 260.120115; found 260.120040.

3-Phenyl-1-(*o*-tolyl)propan-1-one (17): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and (2-methylphenyl)boronic acid (**2g**) (163 mg, 1.20 mmol) using DPPF (19.4 mg, 0.035 mmol) as the ligand. Purification by column chromatography (Al_2O_3, ethyl acetate/hexane, 5:95) afforded compound **17** (146 mg, 65%) as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ = 2.46 (s, 1 H), 3.03 (t, *J* = 7.7 Hz, 2 H), 3.22 (t, *J* = 7.7 Hz, 2 H), 7.08−7.40 (m, 8 H), 7.60 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 203.3 ppm. MS (EI): *m*/*z* (%) = 224 (33) [M^+], 209 (15), 131 (1), 119 (100), 91 (38). HRMS (EI): calcd. for $C_{16}H_{16}O$ [M^+]: 224.120115; found 224.120234.

1-(Furan-2-yl)-3-phenylpropan-1-one (18): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and 2-furanylboronic acid (**2h**) (134 mg, 1.20 mmol) using triphenylphosphane (18.4 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 20:80) afforded compound **18** (94 mg, 47%) as a colorless oil. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.04 (t, *J* = 7.0 Hz, 2 H), 3.14 (t, *J* = 7.0 Hz, 2 H), 6.51 (m, 1 H), 7.15−7.31 (m, 6 H), 7.55 (s, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 29.7, 40.1, 112.2, 116.9, 126.1, 128.4, 128.5, 140.9, 146.3, 152.6, 188.4 ppm. MS (EI): *m*/*z* (%) = 200 (100) [M^+], 181 (7), 171 (15), 153 (10), 104 (45). HRMS (EI): calcd. for $C_{13}H_{12}O_2$ [M^+]: 200.083729; found 200.083676.

3-Phenyl-1-(thiophen-2-yl)propan-1-one (19): The ketone was obtained according to the general procedure from 3-phenylpropionic acid (**5b**) (150 mg, 1.00 mmol) and 3-thiophenylboronic acid (**2i**) (153 mg, 1.20 mmol) using tris(*p*-methoxyphenyl)phosphane (24.7 mg, 0.07 mmol) as the ligand. Purification by column chromatography (silica gel, ethyl acetate/hexane, 20:80) afforded compound **19** (155 mg, 72%) as a white solid. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.04 (t, *J* = 7.0 Hz, 2 H), 3.20 (t, *J* = 7.0 Hz, 2 H), 7.15−7.31 (m, 6 H), 7.54 (m, 1 H), 8.02 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.0, 41.6, 126.1, 126.3, 126.8, 128.4, 128.5, 131.8, 141.1, 142.1, 193.5 ppm. MS (EI): *m*/*z* (%) = 216 (55) [M^+], 187 (1), 131 (5), 111 (100), 91 (15). HRMS (EI): calcd. for $C_{13}H_{12}OS$ [M^+]: 216.060887; found 216.060995. $C_{13}H_{12}OS$ (216.3): calcd. C 72.19, H 5.59; found C 72.11, H 5.49.

Acknowledgments

We thank M. Rössig and L. Winkel for technical assistance, Prof. Dr. M. T. Reetz for generous support and constant encouragement, and the DFG, the FCI, and the BMBF for financial support. We also thank W. Wisniewski for performing the NMR experiments for the kinetic studies.

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Received April 9, 2002
[O02195]