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Ruthenium Catalyzed Decarbonylative Arylation at sp^3 Carbon Centers in Pyrrolidine and Piperidine Heterocycles

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Abstract: This paper describes the development of a new catalytic transformation, the ruthenium-catalyzed decarbonylative arylation of cyclic 2-amino esters, which replaces the ester group with an aryl ring at the sp^3 carbon center. For example, proline ester amidine **1** is converted to 2-arylpyrrolidine **3** in the presence of arylboronic acids or esters as arene donors and $Ru_3(CO)_{12}$ as the catalyst. This process provides a rapid access to a variety of 2-arylpyrrolidines and piperidines from commercially available proline, hydroxyproline, and pipecolinate esters. The examination of the substrate scope also showed that many arene boronic acids and boronate esters serve as coupling partners. The high chemoselectivity of this process was demonstrated and ascribed to the significant rate difference between the decarbonylative arylation and the C−H arylation. The decarbonylative arylation complements the C−H arylation, since the latter process lacks control over the extent of functionalization, affording a mixture of *mono*- and *bis*-arylpyrrolidines. When applied in tandem, these two processes provide 2,5-diarylpyrrolidines in two steps from the corresponding proline esters. It was also demonstrated that the required amidine or iminocarbamate directing group fulfills two major functions: first, it is essential for the ester activation step, which occurs via the coordination-assisted metal insertion into the acyl C−O bond; second, it facilitates the decarbonylation, via the stabilization of a metallacycle intermediate, assuring the formation of the 2-arylated products instead of the corresponding ketones observed before by others.

Introduction

Saturated cyclic amines are indispensable building units of biologically active compounds, including alkaloids, pharmaceuticals, and research probes.[1] Accordingly, many different approaches to the functionalization of these systems via C−H bond cleavage have been developed, utilizing a wide spectrum of known chemical reactivity.[2] However, with the exception of carbene insertion chemistry,[3] there are only a few examples of catalytic methods based on homogeneous transition metal complexes.[2]

We have recently reported the ruthenium-catalyzed arylation of sp^3 C−H bonds at the α-position of saturated cyclic amines with aryl boronates as arene donors.[4] In the course of exploring the scope of this method, we discovered a new catalytic transformation, the decarbonylative arylation of esters at sp^3 carbon centers. Specifically, subjection of the proline ester amidine **1** to the C−H arylation protocol did not lead to the formation of product **2**, but instead resulted in the replacement of the carboxylate moiety with the phenyl ring, affording α-phenyl amidine **3a** as the major product (Scheme 1).

As a mechanistic rationale for this transformation, we propose that the reaction is initiated by the directing group-assisted insertion of ruthenium metal into the acyl−O bond of the ester, forming an acyl−metal−alkoxide complex, which undergoes CO extrusion to afford the key intermediate alkoxide **5a** (Figure 1). A similar intermediate is also formed in the C−H arylation pathway, via the sequential metal insertion into the C−H bond and ketone insertion into the metal hydride. Thus, both pathways converge at the point of the alkyl−alkoxide complex **5a**/**5b**, which participates in transmetallation with phenyl boronate ester and reductive elimination to yield the product **6** (Figure 1).

Activation of carboxylic esters via transition metal insertion into the acyl carbon−oxygen bond has been demonstrated and utilized in catalytic transformations of these common functional groups.[5] Most notably, 2-pyridinylmethyl esters can be converted to the corresponding ketones via the coupling with arene boronate esters in the presence of $Ru_3(CO)_{12}$ as the catalyst. Similarly, ruthenium-catalyzed reductive decarboxylation of these esters was reported with ammonium formate or silane as the reducing agents.[6] The importance of the pyridine ring for the chelation-assisted activation of the ester was demonstrated.

(1) 2-Arylpyrrolidines and piperidines exhibit potent biological activity, particularly in the CNS. For examples, see: Elliot, R. L.; Kopeka, H.; Lin, N.-H.; He, Y.; Garvey, D. S. *Synthesis* **1995**, 772−774.
(2) For an excellent recent review, see: Campos, K. R. *Chem. Soc. Rev.* **2007**, *36*, 1069−1084.
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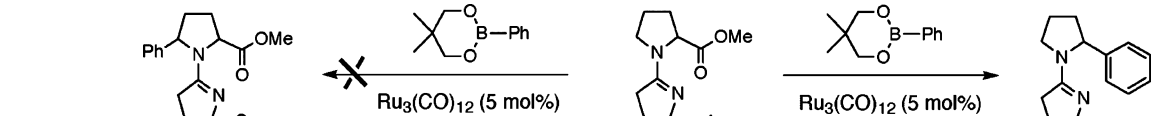
(6) (a) Chatani, N.; Tatamidani, H.; Ie, Y.; Kakiuchi, F.; Murai, S. *J. Am. Chem. Soc.* **2001**, *123*, 4849−4850. (b) Tatamidani, H.; Yokota, K.; Kakiuchi, F.; Chatani, N. *J. Org. Chem.* **2004**, *69*, 5615−5621. (c) Ruthenium-mediated decarbonylation of methyl benzoate (unactivated ester) has been reported: Hiraki, K.; Kira, S.; Kawano, H. *Bull. Chem. Soc. Jpn.* **1997**, *70*, 1583−1592.

10.1021/ja072577n CCC: $37.00

Scheme 1. Decarbonylative Arylation Proceeds in Preference to the C−H Arylation



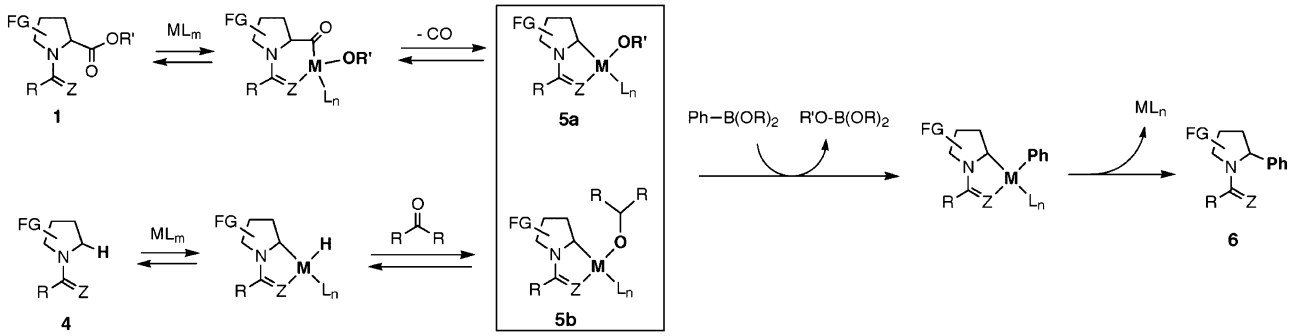


Figure 1. Proposed mechanistic rationale for the new decarbonylative arylation at sp³ carbon centers and its relationship to the sp³ C−H arylation. Both transformations access a similar metal alkoxide intermediate (e.g., **5a**/**5b**), which undergoes transmetallation and C−C bond formation to afford the product (e.g., **6**).

Also, palladium-catalyzed couplings of activated carboxylate esters with arylboronate esters, to produce aryl ketones,[7,8] and with alkenes, to afford the Heck coupling products, were reported.[9] Moreover, carboxylic anhydrides as activated substrates were reported to undergo decarbonylative arylation with arene boronates and other arene donors.[10]

The catalytic decarboxylative transformation of allyl- and benzyl-esters belongs to a mechanistically distinct class of reactions, initiated by the cleavage of the C−O bond linking the allyl group and acyloxy moiety, leading to a loss of CO_2 and formation of new C−C bonds.[11] Catalytic cross-couplings of free arene carboxylic acids with haloarenes and alkenes have recently been reported; these reactions also proceed via a decarboxylative mechanism.[12]

To the best of our knowledge, the decarbonylative arylation disclosed here represents a new catalytic transformation, achieving a direct substitution of an unactivated ester with an aryl ring at the sp³ carbon center. From a synthetic perspective, this reaction enables regioselective preparation of *mono*-arylated nitrogen heterocycles starting from readily available cyclic α-amino esters (e.g., proline, hydroxyproline, pipecolinic acid esters) and, thus, complements the C−H arylation method which provides a mixture of *mono*- and *bis*-arylated products (Figure 2). The "overfunctionalization" of substrates containing two C−H bonds of similar reactivities is a common problem of many catalytic directed C−H functionalization processes, developed for both aromatic and saturated substrates.[13] The significant difference in rates between the decarbonylative arylation and the C−H arylation allows for selective synthesis of monoarylated amines and thus represents a promising alternative for the preparation of these compounds under neutral catalytic conditions. In the following pages, we describe the development and the scope of this transformation.

Results

Optimization of Reaction Conditions and Arene Donor Substrate Scope. Guided by the mechanistic rationale provided above, the reaction conditions were optimized. With regard to the catalyst, only low-valent ruthenium complexes afford the desired product. $Ru_3(CO)_{12}$ is the best catalyst; $RuH_2(CO)(PPh_3)_3$ is less effective, showing lower reaction rates as well as side product formation. In accord with the mechanistic proposal, the ketone reagent (required for the C−H arylation process, Figure 1) is not needed. Both arylboronic acids and esters can be used as coupling partners. The best results for arylation with arylboronate esters are achieved in *m*-xylene at 130 °C employing 1 equiv of ester; under these conditions, the reaction is completed within several hours. Arylation with arylboronic acids gave the best results when performed in DMF employing a slight excess of acid (1.1 equiv). However, there was no clear trend in yields when using arylboronic acids. For example, phenyl-, 4-fluorophenyl-, and 4-(dimethylamino)-phenylboronic acids gave yields superior to those obtained with corresponding *neo*-pentanediol derived esters (Table 1, formation of **3a**, **3b**, **3f**), whereas 4-(trifluoromethyl)phenyl- and indole-5-boronic acids (Table 1, formation of **3d**, **3k**) gave inferior amounts of arylation products. These results can be attributed to differences in stability between free boronic acids and esters under the reaction conditions. Importantly, since CO is released as a byproduct, the reaction shows lower efficiency when conducted in lower boiling solvents, such as dioxane or

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(12) (a) Catalytic decarboxylative arylation of free carboxylic acids with haloarenes has recently been reported: Forgione, P.; Brochu, M.-C.; St-Onge, M.; Thesen, K. H.; Bailey, M. D.; Bilodeau, F. *J. Am. Chem. Soc*. **2006**, 128, 11350−11351. (b) Gooβen, L. J.; Deng, G.; Levy, L. M. *Science* **2006**, *133*, 662−664. Catalytic cross-coupling of free arene carboxylic acids with alkenes (decarboxylative olefination): (c) Myers, A. G.; Tanaka, D.; Mannion, M. R. *J. Am. Chem. Soc*. **2002**, *124*, 11250−11251. (d) Tanaka, D.; Romeril, S. P.; Myers, A. G. *J. Am. Chem. Soc*. **2005**, *127*, 10323−10333.

(13) Kakiuchi, F.; Chatani, N. *Adv. Synth. Catal*. **2003**, *345*, 1077−1101.

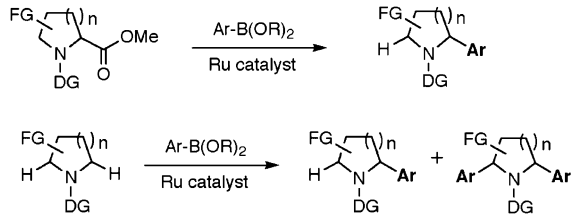
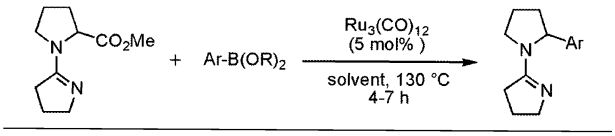
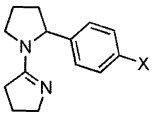


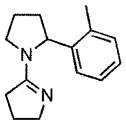
Figure 2. Significant rate difference between the decarbonylative arylation and the C−H arylation enables synthesis of *mono*-arylated products. Formation of *bis*-substituted side products is a shortcoming of many catalytic directed C−H functionalization methods. DG = directing group.

Table 1. Decarbonylative Arylation of Methyl Prolinate **1**[a]

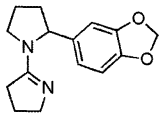




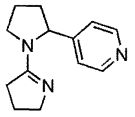
	X	Yield, %
3a	H	55 (75)
3b	F	63 (76)
3c	Cl	60
3d	CF_3	57 (17)
3e	OMe	60
3f	NMe_2	64 (77)



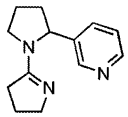
3g, 59%[b]



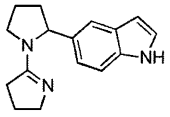
3h, 57%



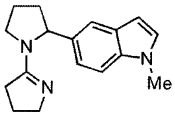
3i, 64%[c]



3j, 66%[d]



3k, 48% (<5%)



3l, 48%[c,e]

[a] Coupling with boronate esters: 0.9−1 equiv of ester (*neo*-pentanediol derived unless otherwise stated), xylene; yields are based on esters. Coupling with arylboronic acids: 1.1 equiv of acid, DMF; yields are based on amidines and given in parentheses. [b]Performed in a microwave reactor at 180 °C for 30 min. [c]Pinacol-derived ester used. [d]Reaction time 18 h. [e]Reaction time 48 h.

toluene, which necessitates the use of a sealed vessel. With the optimized procedure in hand, we examined the scope of the new transformation beginning with the arene boronate substrates (Table 1).

The present method is compatible with a variety of aryl and heteroaryl boronate ester donors. The electronic nature of the boronates had no significant effect on the efficiency of the transformation. Specifically, aryl boronates containing both electron-withdrawing substituents (F, Cl, CF_3) and electron-donating counterparts (OMe, NMe_2) were successfully coupled with small differences in the yield or reaction time. Notably, pyridine donors, capable of coordinating to the ruthenium metal and competing with the amidine directing group, were well tolerated (compounds **3i**, **3j**). Although the coupling with *ortho*-substituted boronic ester to form **3g** was considerably slower

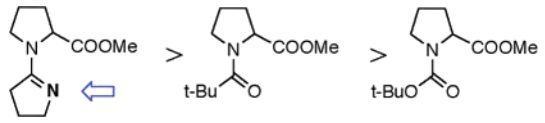


Figure 3. Cyclic amidine is a superior directing group.

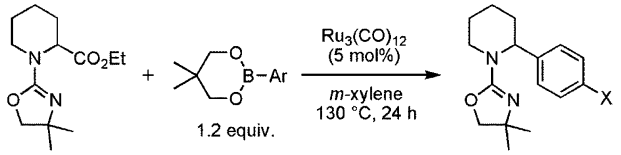
under the standard conditions, a good yield of the product was obtained by performing the reaction in a microwave reactor at 180 °C. Introduction of the more sterically encumbered mesityl ring failed. Also, an *ortho*-fluoro substituent was not tolerated. Small quantities of the reductive decarboxylation product 5-pyrrolidin-1-yl-3,4-dihydro-2*H*-pyrrole and the 1,5-*bis*-arylated material were detected in some reaction mixtures (<5% by GC). As expected, addition of an excess of aryl boronate resulted in an increased amount of *bis*-arylated byproducts, formed by the C−H arylation of the product (see above, Figure 2).[4] *Bis*-arylated products are not formed in the case of arylboronic acids. Interestingly, the reaction rate and yield were significantly affected by the nature of the ester backbone of the aryl donor (between pinacol- and *neo*-pentanediol-derived esters), however, in an irregular manner. For example, formation of product **3a** was approximately ten times slower using the pinacol-derived ester compared to the neopentanediol-derived substrate. In contrast, the synthesis of **3i** was more efficient with the pinacol-derived boronate.

Directing Groups and α-Amino Ester Substrates. The Scope. The amidine group proved to be far superior to other commonly employed directing groups. The corresponding carbamates and amides gave <10% of the arylation product, presumably due to the lower coordination ability of these groups compared to the cyclic amidine (Figure 3).

The next key issue was whether the decarbonylative arylation protocol could be applied to other saturated heterocyclic esters with particular focus on six-membered cyclic substrates. The ethyl ester of piperidine-2-carboxylate is commercially available, however we were unable to prepare the requisite amidine starting material due to its instability (caused by intramolecular attack of the ester by the amidine nitrogen). A search for a viable directing group identified the 4,4-dimethyl-4,5-dihydro-1,3-oxazolyl moiety as a suitable candidate. The corresponding ethyl pipecolinate derivative **7** was prepared in high yield (see Supporting Information) and submitted to the reaction conditions. Gratifyingly, this new substrate underwent the decarbonylative arylation, affording products **8a**−**d** in yields comparable to those obtained with the proline-based substrates (Scheme 2); however, longer reaction times were necessary. Reductive decarboxylation of **7** was identified as a major side reaction, yielding the corresponding piperidine in 10−20%. The better stability and lower reactivity of substrate **7** can in major part be ascribed to the lower basicity of the iminocarbamate in comparison to the amidine group. Presumably for the same reason, the aryl donor containing a dimethylamino group required a higher reaction temperature (**8d**) while the pyridyl boronates gave no desired products at all. Phenylboronic acid was substantially less effective than the corresponding boronate ester (Scheme 2, formation of **8a**), due to the lower stability of the acids under prolonged heating in the reaction medium.

The decarbonylative arylation of substrates derived from methyl piperazine-2-carboxylate also gave the desired products, although at higher catalyst loading and higher temperature when compared to piperidine and pyrrolidine substrates (Scheme 3).

Scheme 2. Decarbonylative Arylation of Ethyl Pipecolinate Substrate

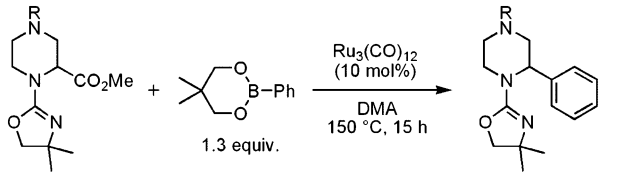


7

	X	%
8a	H	55 (35[a])
8b	Cl	56
8c	OMe	40[b]
8d	NMe_2	45[c]

[a] Performed with phenylboronic acid in DMA; GC yield. [b]Performed at 140 °C; 1.5 equiv of boronate ester used. [c]Reaction conditions: DMA, 150 °C, 15 h.

Scheme 3. Decarbonylative Arylation of Methyl Piperazine-2-carboxylate Derivatives

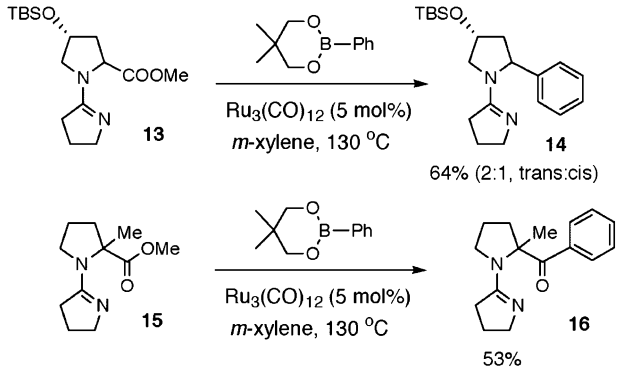


9 R = Cbz
10 R = Bn

11 R = Cbz 38%
12 R = Bn 20%[a]

[a] NMR yield; concomitant formation of corresponding 2,3-dehydrogenated product observed.

Scheme 4. Catalytic Arylation Is Chemoselective



The low reactivity and the relative facility of undesired competitive pathways (reductive decarbonylation and elimination) account for low efficiency. Again, the presence of an amino group in the starting material (e.g., **10**) led to a significant inhibition of the reaction. Despite the modest yields, these are encouraging results as the catalytic C−H arylation of piperazine substrates has hitherto failed completely. The arylation of the corresponding acyclic amino ester substrates was also unsuccessful.

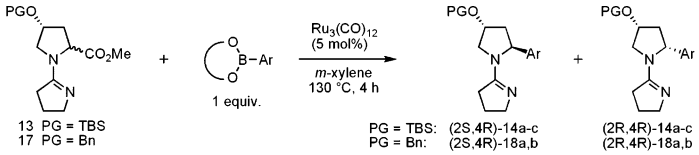
Selectivity of the Decarbonylative Arylation. The high chemoselectivity of the arylation process was demonstrated by the conversion of compound **13** (a 1:1 mixture of diastereomers) to product **14** (Scheme 4 and Table 2). No other regioisomers or *bis*-arylated compounds were detected in the reaction mixture. Also, the chiral center at the 4-position (carbon bearing the TBSO-group) was intact (the stereochemistry in the 2-position will be discussed below). We also examined the arylation at a tertiary center by submitting 2-methylprolinate ester **15** to the arylation protocol. In this case, phenyl ketone **16** was formed in 53% yield with no detectable amounts of the decarbonylated arylation product (Scheme 4). Also, no C−H arylation product was detected. Apparently, the steric hindrance at C-2 prevents the decarbonylation and formation of a tertiary carbon−ruthenium bond; instead, the acyl−ruthenium−alkoxide intermediate undergoes the transmetallation to furnish the phenyl ketone. This result supports the mechanistic proposal where the ester activation is facile while the subsequent step(s) (either the transmetallation or reductive elimination) is slow. In stark contrast, the related C−H arylation is initiated by the slow C−H insertion step (Figure 1). This hypothesis explains the dramatic differences between these transformations; the C−H arylation of symmetrical substrates (e.g., pyrrolidine-amidine) affords a mixture of *mono*- and *bis*-arylation products, and the unsymmetrical β-substituted substrates (e.g., 3-hydroxypyrrolidine-derived substrate) give a mixture of *mono*-arylated regioisomers in addition to the *bis*-arylated product.

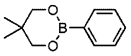
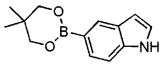
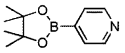
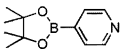
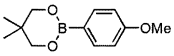
From the synthetic angle, the decarbonylative arylation complements the C−H arylation method by addressing its shortcomings related to the "overfunctionalization". When applied in a sequential manner, these two methods enable two-step preparation of unsymmetrical 2,5-*bis*-arylpyrrolidines (Scheme 5). Both the amidine and the iminocarbamate products can be efficiently cleaved to yield the free amines by treatment with NH_2NH_2/AcOH or NH_2NH_2/TFA at elevated temperatures (see Supporting Information). Notably, the deprotection procedures are compatible with a commonly employed TBS protecting group.

Stereochemical Issues. In addition to the high chemoselectivity of the arylation reaction, it is also compatible with chiral centers in the 4-position (Scheme 4 and Table 2). However, the process is not stereoselective at the 2-position. The epimerization of the ester-bearing center occurs at the stage of directing group installation as elucidated in the preparation of hydroxyproline derivatives **13** and **17** (Table 2). The crude reaction mixture resulting from heating a single diasteromer of the O-protected hydroxyprolinate ester with 5-methoxy-3,4-dihydro-2*H*-pyrrole consisted of nearly an equimolar ratio of diastereomers of the corresponding product (see Supporting Information; optically pure methyl prolinate was also racemized during the preparation of the amidine substrate). Moreover, diastereomeric hydroxyproline derivatives (*cis*-**13**, *trans*-**13**) underwent interconversion on silica gel or even upon standing at room temperature. Interestingly, the benzyl protected analogues (*cis*-**17**, *trans*-**17**) showed no epimerization at ambient temperature, and each isomer could be obtained diastereomerically pure *via* column chromatography.

Nevertheless, amidines **13** and **17** can be arylated using the developed protocol in good yields, providing a mixture of *cis* and *trans* isomers that are readily separable *via* column chromatography (Table 2). The *trans*/*cis* ratio of products **14a**−**c** obtained by the arylation of the diastereomeric mixture **13** ranged from 1.3:1 to 1.9:1. In the arylation of diastereomerically pure compound (2*S*,4*R*)-**17** (*trans*), the corresponding ratio was increased to 2.8:1 (entry 5). When the other diastereomer (2*R*,4*R*)-**17** (*cis*) was used, the ratio decreased to almost an equimolar level (entry 6). This trend suggests that the arylation process itself may be stereospecific if the competitive thermal epimerization of the substrate could be minimized.

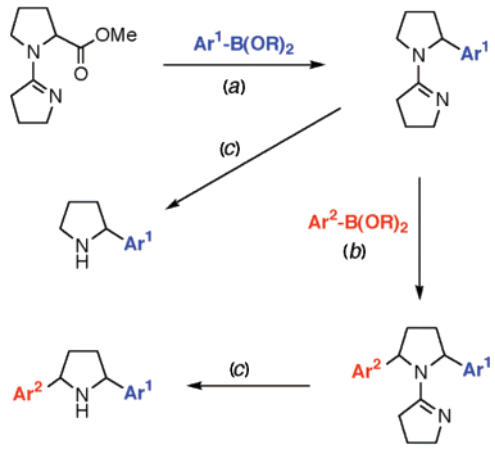
Table 2. Decarbonylative Arylation of Hydroxyproline Derivatives



Entry	Starting material	Boronate	Products	trans/cis ratio	Yield, %
1	(4*R*)-**13**		(2*S*,4*R*)-**14a**[a] (2*R*, 4*R*)-**14a**	1.8:1	64 (61[b])
2	(4*S*)-**13**		(2*R*,4*S*)-**14a**[c] (2*S*, 4*S*)-**14a**	1.9:1	58
3	(4*R*)-**13**		(2*S*,4*R*)-**14b** (2*R*, 4*R*)-**14b**	1.4:1	50
4	(4*R*)-**13**		(2*S*,4*R*)-**14c** (2*R*,4*R*)-**14c**	1.3:1	75
5	(2*S*,4*R*)-**17**		(2*S*,4*R*)-**18a**	2.8:1	68
6	(2*R*,4*R*)-**17**		(2*R*,4*R*)-**18a**	1.1:1	72
7[d]	(2*S*,4*R*)-**17**		(2*S*,4*R*)-**18b** (2*R*,4*R*)-**18b**	2.8:1	65

[a] >99% ee as determined *via* Mosher's amide. [b]Performed with 1.1 equiv of phenylboronic acid in DMF. [c]93% ee as determined *via* Mosher's amide. [d]Performed at 140 °C for 2 h.

Scheme 5. Sequential Arylation of Pyrrolidine Systems[a,b]

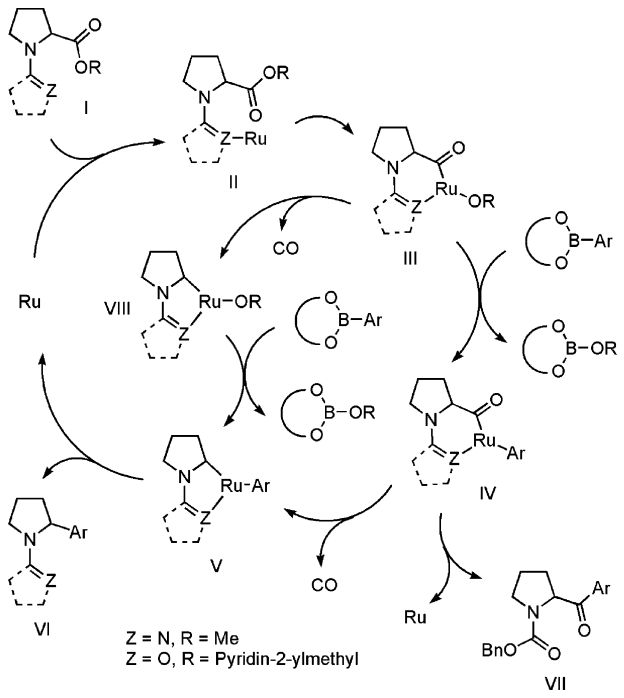


[a] Decarbonylative arylation complements the C−H arylation method. [b]Conditions: (*a*) Ru_3CO_{12} (5 mol %), xylene or DMF, 130 °C. (*b*) Ru_3CO_{12} (3.3 mol %), pinacolone, 150 °C. (*c*) NH_2NH_2/AcOH or NH_2NH_2/TFA, ethanol, 120 or 140 °C.

In summary, the decarbonylative arylation of esters **13** and **17** enables a facile preparation of both the *cis* and *trans* series of 4-hydroxy-2-aryl-pyrrolidine derivatives from a single precursor.

Mechanistic Proposal. The Key Role of the Directing Group. We propose the following mechanistic hypothesis that is consistent with both the results described in this paper and the ideas put forth by others (Scheme 6).[6−8] The catalytic process is initiated by the activation of the ester, via insertion of ruthenium into the acyl−O bond, promoted by coordination of the metal to the directing group. The resulting acyl, alkoxo-ruthenium complex **III** may undergo transmetallation with phenyl boronate to produce acyl, aryl-ruthenium intermediate **IV** along with trialkyl borate, which is followed by reductive elimination, to furnish ketone product **VII**. Indeed, an analogous

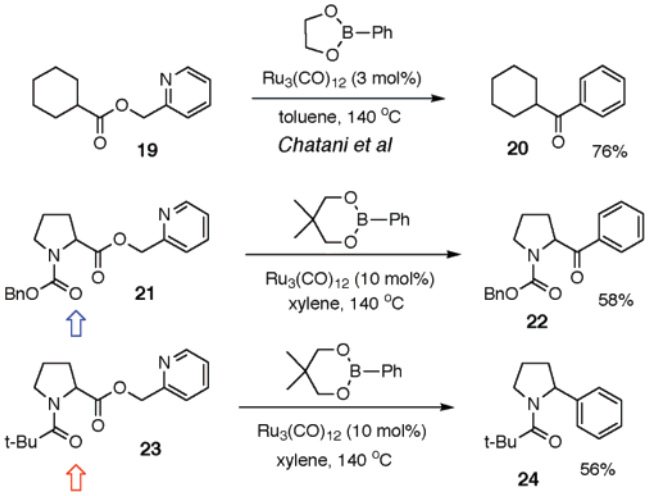
Scheme 6. Proposed Mechanism for the Reaction of Esters with Aryl Boronates Catalyzed by Ru_3CO_{12}



mechanistic sequence was proposed by Chatani and colleagues for the preparation of ketones from esters containing the pyridine-directing group appended to the carboxylic oxygen (**19** → **20**, Scheme 7).[6]

However, complex **III** may undergo decarbonylation, resulting in the formation of new intermediate **VIII**, which would proceed via transmetallation and reductive elimination to furnish the α-arylation product **VI**. The latter pathway is favored in the presence of a strongly coordinating directing group, such as the amidine group described here, due to the stabilization of

Scheme 7. Importance of Directing Group



the five-membered metallacycle intermediate **VIII** (assuming that the ruthenium cluster fragments to mononuclear ruthenium catalyst). It should be noted that product **VI** could also be accessed via intermediate **IV**, that is, via a sequence where the transmetallation precedes the decarbonylation. Either way, *the directing group fulfills several major roles; it is crucial for the ester activation, but it also affects the product distribution*.

To further support this proposal, we prepared esters **21** and **23** with the goal of separating the ester activation from the metallacycle stabilization by installing two directing groups (Scheme 7). Remarkably, the carbamate-protected substrate **21** gave ketone **22** as the only islolated product, while the amide-protected substrate furnished the 2-phenylpyrrolidine compound **24**. A seemingly small structural change led to a complete switch in the reaction outcome. These observations are consistent with the known trends: namely, carbamates are weaker directing groups than amides due to the weaker coordination to transition metals.

Currently, there is no structural information available for the active metal species because all attempts to isolate relevant intermediates have so far been unsuccessful. The global mechanism is supported by volumetric analysis that showed that 1 equiv of CO was released in the course of the arylation. We also confirmed that the ketone is not an intermediate in the decarbonylative arylation process (Supporting Information).

Conclusions

In this paper, we described the discovery and development of catalytic decarbonylative arylation of cyclic α-amino esters. This process provides rapid access to a variety of 2-arylpyrrolidines and piperidines from commercially available proline or picolinic acid derivatives in a selective manner. This reaction is complementary to the recently introduced sp^3 C−H arylation process, as it addresses one key shortcoming of the latter process, poor control over the extent of C−H functionalization (*mono*- and *bis*-arylation) and the regioselectivity (with unsymmetrical substrates). Applied in tandem, the decarbonylative arylation and the C−H arylation enable the synthesis of 2,5-diarylpyrrolidines from proline derivatives.

The product formation analysis afforded evidence that supports the proposed mechanistic hypothesis where the catalytic cycle is initiated by chelation-assisted ester activation, followed by decarbonylation and transmetallation of the respective intermediates, to ultimately produce the α-arylated product and regenerated catalyst. The critical importance of a strong directing group was demonstrated, facilitating not only the ester activation but also the decarbonylation, and thus assuring the formation of the α-arylated product instead of the ketone. This insight may be useful for the future design of catalytic arylation methods.

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Supporting Information Available: Experimental protocols and spectral characterization of discussed compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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