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One-Pot Preparation of Tricyclo[5.2.2.$0^{4,9}$]undecanes via Cu-Catalyzed Asymmetric Carboboration of Cyclohexadienone-Tethered Allenes

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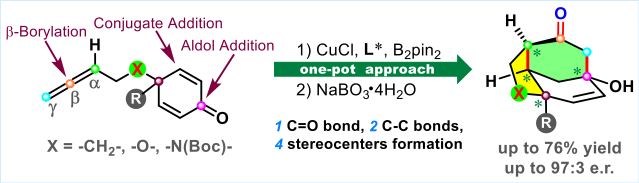
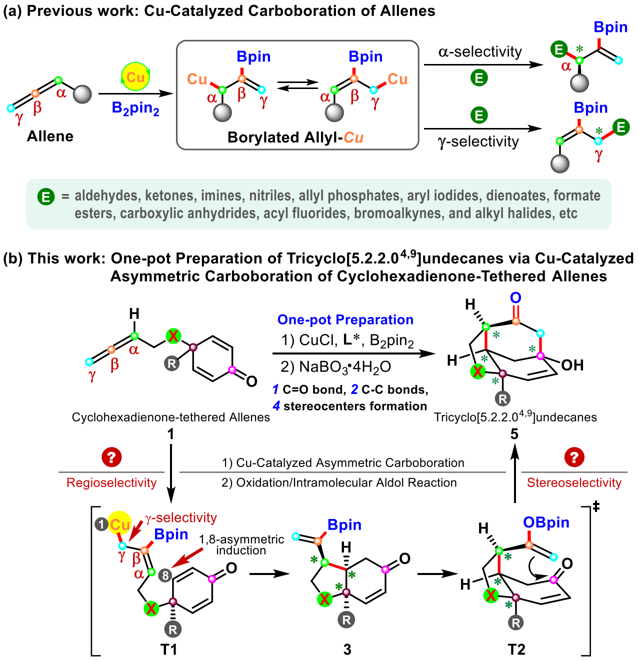
ABSTRACT: The Cu-catalyzed asymmetric carboboration of cyclohexadienone-tethered allenes has been achieved through regioselective *β*-borylation of the allenes and subsequent conjugate addition to cyclohexadienones, affording *cis*-bicyclic frameworks with acceptable yields and high to excellent enantioselectivities. Further conjugate borylation of the carboboration products proved to be a favorable kinetic resolution process, which improved the overall enantioselectivity. Finally, one-pot preparation of highly enantioenriched tricyclo[5.2.2.$0^{4,9}$]undecanes was developed from the cyclohexadienone-tethered allenes through *β*-borylation/1,4-addition and subsequent tandem oxidation/intramolecular aldol reaction.



Tricyclo[5.2.2.$0^{4,9}$]undecanes represent a unique framework existing in a number of natural products,[1] for instance, (+)-upial,[1a] JBIR-85,[1b] fusidilactone C,[1c] garcixanthochymone C,[1d] and shinjulactone C.[1e] Because of their structural complexity, efficient synthetic approaches to such intriguing bridged tricyclic skeletons are extremely rare. Recently, significant progress has been made in borylcopper (Cu−B)-catalyzed borylation of allenes,[2] especially carboboration of allenes (Scheme 1a).[3−9] The reactions of Cu−B species with allenes result in useful *β*-borylated allylcopper intermediates, which subsequently undergo a variety of transformations with different carbon electrophiles: aldehydes, ketones, imines, and nitriles for 1,2-addition;[3] allyl phosphates for boroallylation;[4] aryl iodides for boroarylation;[5] dienoates for 1,6-addition;[6] formate esters, carboxylic anhydrides, and acyl fluorides for boroacylation;[7] bromoalkynes for boroalkynylation;[8] and alkyl halides for alkylboration.[9] Despite the above notable advances, the 1,4-addition of *β*-borylated allylcopper especially to *α*,*β*-unsaturated ketones has never been uncovered,[10] due to the fact that the six-membered chairlike transition state makes the 1,2-addition to ketone more favorable.[3a] Herein, we present Cu-catalyzed asymmetric carboboration of cyclohexadienone-tethered allenes,[11] which involves asymmetric 1,4-addition of *β*-borylated allylcopper to enone, thereby establishing a one-pot preparation of highly enantioenriched tricyclo[5.2.2.$0^{4,9}$]undecanes via the aforementioned carboboration and subsequent tandem oxidation/intramolecular aldol reaction (Scheme 1b).

This one-pot process starts from the Cu-catalyzed regioselective *β*-borylation of the allene moiety as the direct conjugate borylation is restrained from the neighboring steric

Scheme 1. Strategic Design for the One-Pot Preparation of Tricyclo[5.2.2.$0^{4,9}$]undecanes



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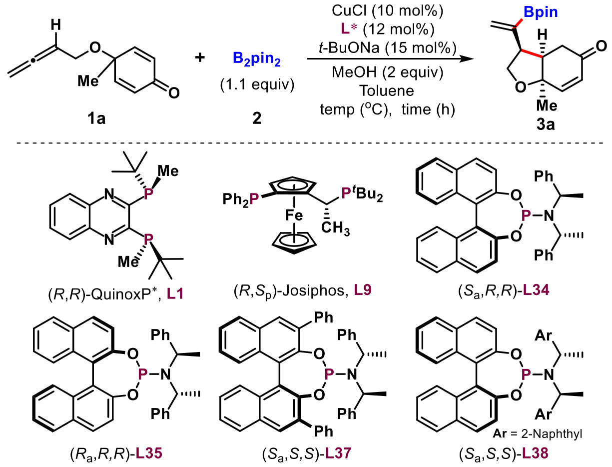
congestion (Scheme 1b).[12] The Cu−B addition places the Cu at the less hindered site of allene. Both γ-selective copper addition and the highly reactive nature of cyclohexadienone could nicely prevent the competitive β-elimination pathway.[11a,13] Thus, the subsequent intramolecular 1,4-addition of **T1** affords chiral *cis*-bicyclic frameworks **3**. The next tandem oxidation/intramolecular aldol reaction furnishes the expected tricyclo[5.2.2.0^{4,9}]undecanes **5**, probably due to the close location of this enol boronate moiety to the ketone functionality in **T2**. However, the multiple control of overall regio-, diastereo-, and enantioselectivity (1,8-asymmetric induction) remains extremely challenging in these domino processes.

With these considerations in mind, a set of representative chiral ligands was evaluated for this Cu-catalyzed asymmetric carboboration of cyclohexadienone-tethered allene **1a**, and selected results were summarized in Table 1.[14] Initially, the conventionally used ligands (*R*,*R*)-QuinoxP* (**L1**) and (*R*,*S*$_p$)-Josiphos (**L9**) were tested.[15] Fortunately, the desired product **3a** was obtained, albeit in moderate diastereoselectivities and low enantioselectivities (Table 1, entries 1 and 2). Previously, we reported that phosphoramidite ligand **L34** could promote the asymmetric carboboration of 1,6-enynes.[16] However, only 20% yield and moderate er were observed despite the excellent diastereoselectivity in this case (Table 1, entry 3). Next, its diastereoisomeric ligand **L35** was subjected to the same reaction; to our delight, the er of **3a** dramatically rose to 88:12 (Table 1, entry 4). Attempt to increase the size of ligand **L35** to either **L37** or **L38** led to decreased er (Table 1, entries 5 and 6). Lowering the reaction temperature to −15 °C resulted in great improvement of er (Table 1, entries 7−9), and increasing B_2pin_2 (**2**) loading gave rise to further improvement of both yields and enantioselectivities (Table 1, entries 10−12). In particular, moderate yield (45%) and excellent diastereo- and enantioselectivity (>25:1 dr and 95:5 er) were accomplished when 2 equiv of B_2pin_2 was used (Table 1, entry 11). We also found that perfect enantioselectivity (>99.9:0.1 er), but with only 21% yield, was provided when more *t*-BuONa (30 mol %) was used (Table 1, entry 13). The low yield of **3a** might result from second conjugate borylation of excessive B_2pin_2 to **3a** promoted by extra *t*-BuONa.

Table 1. Selected Optimization Studies[a]



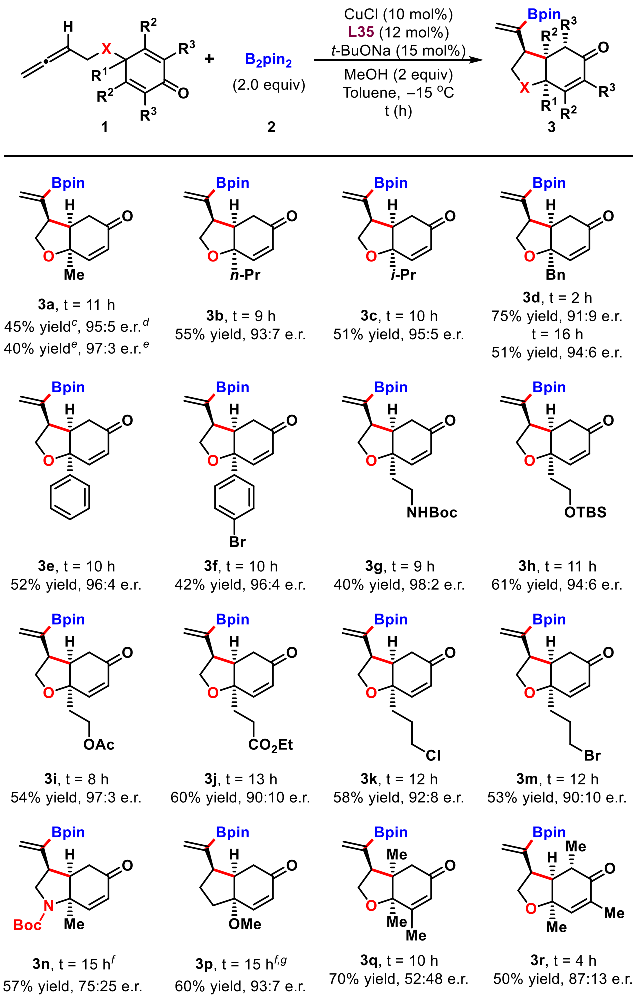
entry	L*	temp (°C)	time (h)	conv[b] (%)	yield (%)	dr	er[e]
1	**L1**	25	9	75	49[c]	17:1[d]	45:55
2	**L9**	25	9	85	53[c]	6:1[d]	64:36
3	**L34**	25	9	50	20[b]	20:1[b]	20:80
4	**L35**	25	14	80	40[b]	20:1[b]	88:12
5	**L37**	25	17	90	40[b]	20:1[b]	41:59
6	**L38**	25	17	75	40[b]	20:1[b]	15:85
7	**L35**	0	19	80	40[b]	20:1[b]	91:9
8	**L35**	−15	19	70	40[b]	20:1[b]	92:8
9	**L35**	−35	22	45	25[b]	20:1[b]	86:14
10[f]	**L35**	−15	21	85	47[c]	>25:1[d]	94:6
11[g]	**L35**	−15	11	90	45[c]	>25:1[d]	95:5
12[h]	**L35**	−15	21	90	53[c]	>25:1[d]	91:9
13[g,i]	**L35**	−15	13	95	21[c]	>25:1[d]	>99.9:0.1

[a] Reactions were performed under an Ar atmosphere. [b] Determined by ^1H NMR of unpurified mixtures. [c] Yield of isolated product **3a**. [d] Determined by ^1H NMR of isolated product **3a**. [e] Determined by HPLC analysis. [f] B_2pin_2 (**2**, 1.5 equiv) was used. [g] B_2pin_2 (**2**, 2.0 equiv) was used. [h] B_2pin_2 (**2**, 3.0 equiv) was used. [i] *t*-BuONa (30 mol %) was used.

With the optimal conditions identified, we next evaluated the scope of cyclohexadienone-tethered allenes **1**. With the R^1 substituent as an alkyl, benzyl, or phenyl group, the reactions proceeded smoothly with moderate to good yields (42%−75%) and good to high enantioselectivities (91:9−96:4 er, Scheme 2, **3a**−**3f**). The absolute configuration of product **3e** was unambiguously determined as (3*R*,3a*R*,7a*R*) by X-ray diffraction analysis. Moreover, as for the benzyl substrate, prolonging the reaction time led to erosion of the yield but slight enhancement of the enantioselectivity (Scheme 2, **3d**), which might be attributed to the further conjugate borylation of excessive B_2pin_2 to **3d**. With a heteroatom (N, O, Cl, and Br) as part of the R^1 substituent in substrates **1**, the reaction yields and er values remained moderate and high, respectively (Scheme 2, **3g**−**3m**). It is worth mentioning that the highly reactive bromoalkyl group was comfortably tolerated without any observation of nucleophilic substitution product in the transformation (Scheme 2, **3m**).[9b] For the N- and C-linked substrates **1n** and **1p**, which were less reactive, the corresponding carboboration products, *cis*-hydroindole **3n** and *cis*-hydroindene **3p**, could also be obtained with moderate to high enantioselectivities at room temperature. For β-methyl-substituted cyclohexadienone substrate **1q**, almost racemic product **3q** was obtained in good yield, which was probably attributed to the steric effect in the conjugate addition process, whereas moderate yield and enantioselectivity could be achieved when α-methyl-substituted cyclohexadienone substrate **1r** was used (Scheme 2, **3r**). As shown in Scheme 2, the mild reaction conditions are generally compatible with a wide range of functional groups, such as amine, silyl ether, ester, chloride, and bromide, providing a versatile platform for further synthetic manipulations.

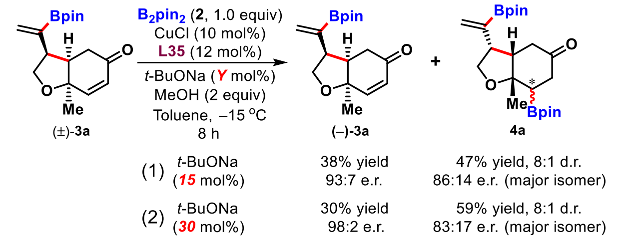
To confirm that the second conjugate borylation of carboboration products **3** was a favorable kinetic resolution process,[11b] i.e., the minor enantiomer of the carboboration product was consumed faster by excessive B_2pin_2 through second conjugate borylation, racemic product (±)-**3a** was subjected to the standard reaction conditions (Scheme 3). In line with our expectations, the conjugate borylation product **4a** was obtained with 47% yield and 86:14 er and the remaining **3a** was determined to be (−)-**3a** with 38% yield and 93:7 er (Scheme 3, eq 1). When more *t*-BuONa (30 mol %) was used, the yield of (−)-**3a** decreased to 30%; however, the loss was compensated by the achievement of excellent enantioselectivity (98:2 er, Scheme 3, eq 2). This study clearly demonstrated that

Scheme 2. Substrate Scope of Cyclohexadienone-Tethered Allenes[a]



[a] Reactions were performed under an Ar atmosphere. [b] All dr > 25:1 (determined by ^1H NMR analysis of unpurified mixtures). [c] Yield of isolated product **3**. [d] Determined by HPLC analysis. [e] 1.0 mmol scale. [f] At room temperature. [g] **L35** was replaced by (*S*)-BINAP (**L3**).

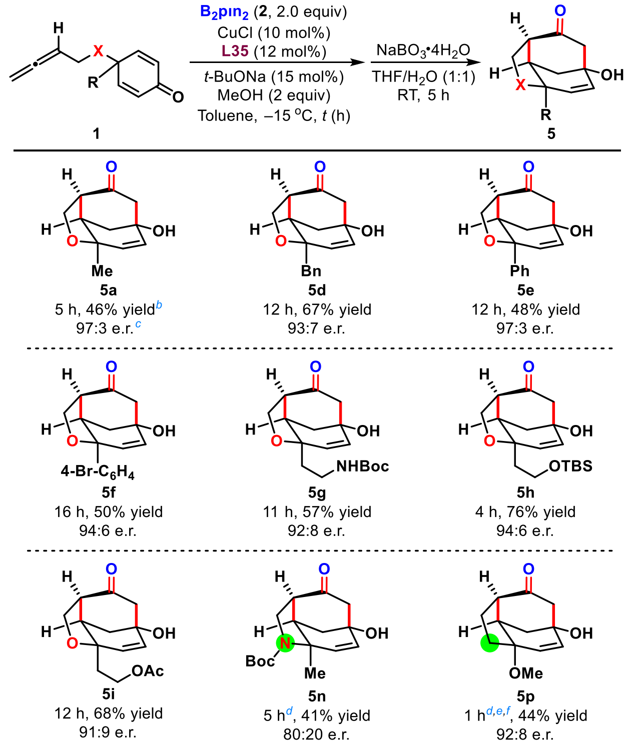
Scheme 3. Kinetic Resolution of (±)-3a via Cu-Catalyzed Conjugate Borylation



the second conjugate borylation of carboboration products was a favorable kinetic resolution process, and this can explain why perfect enantioselectivity of the carboboration reaction could be achieved by adding more base and excessive B_2pin_2 (Table 1, entry 13).

Finally, the one-pot preparation of highly enantioenriched tricyclo[5.2.2.$0^{4,9}$]undecanes was developed from the simple cyclohexadienone-tethered allenes, and the results are illustrated in Scheme 4.[17] With the R substituent as an alkyl, benzyl, or phenyl group, the domino reaction proceeded smoothly to give tricyclo[5.2.2.$0^{4,9}$]-2-oxaundecanes with moderate yields (46%−67%) and high to excellent enantioselectivities (93:7−97:3 er, Scheme 4, **5a**, **5d**, **5e**, and **5f**). With a heteroatom (N and O) as part of R substituent in substrates **1**, the reaction yields and er values remained moderate and high, respectively (Scheme 4, **5g**, **5h**, and **5i**). For the N- and C-linked substrates, **1n** and **1p**, the corresponding tricyclo[5.2.2.$0^{4,9}$]undecanes were obtained with moderate to high enantioselectivities as well (Scheme 4, **5n** and **5p**). The relative configuration of products **5e** and **5f** was determined by the X-ray diffraction analysis of their racemates, respectively.

Scheme 4. One-Pot Preparation of the Highly Enantioenriched Tricyclo[5.2.2.$0^{4,9}$]undecanes[a]



[a] Reactions were performed under an Ar atmosphere. [b] Yield of isolated product **5**. [c] Determined by HPLC analysis. [d] At room temperature. [e] B_2pin_2 (**2**, 1.2 equiv) was used. [f] **L35** was replaced by (*S*)-BINAP (**L3**).

In summary, the first Cu-catalyzed asymmetric carboboration of cyclohexadienone-tethered allene has been successfully established. This tandem reaction proceeded smoothly to afford *cis*-hydrobenzofuran, *cis*-hydroindole, and *cis*-hydroindene frameworks bearing three consecutive carbon chiral centers with good yields and high to excellent enantioselectivities. Adding more base or excessive B_2pin_2 to the aforementioned reaction could increase the enantioselectivity. Such enhancement was mainly caused by the second conjugate borylation of extra B_2pin_2, which was supported by further kinetic resolution studies using racemic carboboration products. Furthermore, the one-pot preparation of highly enantioenriched tricyclo[5.2.2.$0^{4,9}$]undecanes was established directly from the simple cyclohexadienone-tethered allenes via domino processes: *β*-borylation/1,4-addition and subsequent tandem oxidation/intramolecular aldol reaction.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.orglett.0c04191.

> Experimental procedures, spectra for all new compounds, and X-ray crystallographic data for compounds **3e**, (±)-**5e**, and (±)-**5f** (PDF)

Accession Codes

CCDC 1437751−1437753 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Schulte, G.; Scheuer, P. J.; McConnell, O. J. Upial, a sesquiterpenoid bicyclo[3.3.1]nonane aldehyde lactone from the marine sponge Dysidea fragilis. *J. Org. Chem.* **1980**, *45*, 552. (b) Izumikawa, M.; Satou, R.; Motohashi, K.; Nagai, A.; Ohnishi, Y.; Takagi, M.; Shin-ya, K. Naphthoquinone-like Polyketide Isolated from Streptomyces sp. RI-77 and Its Predicted Biosynthetic Pathway. *J. Nat. Prod.* **2011**, *74*, 2588. (c) Krohn, K.; Biele, C.; Drogies, K.-H.; Steingröver, K.; Aust, H.-J.; Draeger, S.; Schulz, B. Fusidilactones, a New Group of Polycyclic Lactones from an Endophyte, Fusidium sp. *Eur. J. Org. Chem.* **2002**, *2002*, 2331. (d) Chen, Y.; Gan, F.; Jin, S.; Liu, H.; Wu, S.; Yang, W.; Yang, G. Adamantyl derivatives and rearranged benzophenones from Garcinia xanthochymus fruits. *RSC Adv.* **2017**, *7*, 17289. (e) Ishibashi, M.; Murae, T.; Hirota, H.; Tsuyuki, T.; Takahashi, T.; Itai, A.; Iitaka, Y. Shinjulactone C, a new quassinoid with a 1*α*, 12*α*:5*α*, 13*α*-dicyclo-9*β*H-picrasane skeleton from ailanthus altissima SWINGLE. *Tetrahedron Lett.* **1982**, *23*, 1205.

(2) For selected reviews on borylcopper-catalyzed borylation of allenes, see: (a) Pulis, A. P.; Yeung, K.; Procter, D. J. Enantioselective copper catalysed, direct functionalisation of allenes via allyl copper intermediates. *Chem. Sci.* **2017**, *8*, 5240. (b) Fujihara, T.; Tsuji, Y. Cu-Catalyzed Borylative and Silylative Transformations of Allenes: Use of *β*-Functionalized Allyl Copper Intermediates in Organic Synthesis. *Synthesis* **2018**, *50*, 1737. For selected recent reviews on borylcopper-catalyzed reactions, see: (c) Talbot, F. J. T.; Dherbassy, Q.; Manna, S.; Shi, C.; Zhang, S.; Howell, G. P.; Perry, G. J. P.; Procter, D. J. Copper-Catalyzed Borylative Couplings with C−N Electrophiles. *Angew. Chem., Int. Ed.* **2020**, *59*, 20278. (d) Whyte, A.; Torelli, A.; Mirabi, B.; Zhang, A.; Lautens, M. Copper-Catalyzed Borylative Difunctionalization of *π*-Systems. *ACS Catal.* **2020**, *10*, 11578. (e) Xue, W.; Oestreich, M. Beyond Carbon: Enantioselective and Enantiospecific Reactions with Catalytically Generated Boryl- and Silylcopper Intermediates. *ACS Cent. Sci.* **2020**, *6*, 1070.

(3) (a) Meng, F.; Jang, H.; Jung, B.; Hoveyda, A. H. Cu-Catalyzed Chemoselective Preparation of 2-(Pinacolato)boron-Substituted Allylcopper Complexes and their In Situ Site-, Diastereo-, and Enantioselective Additions to Aldehydes and Ketones. *Angew. Chem., Int. Ed.* **2013**, *52*, 5046. (b) Zhao, Y.-S.; Tang, X.-Q.; Tao, J.-C.; Tian, P.; Lin, G.-Q. Efficient access to *cis*-decalinol frameworks: copper(I)-catalyzed borylative cyclization of allene cyclohexanediones. *Org. Biomol. Chem.* **2016**, *14*, 4400. (c) Rae, J.; Yeung, K.; McDouall, J. J. W.; Procter, D. J. Copper-Catalyzed Borylative Cross-Coupling of Allenes and Imines: Selective Three-Component Assembly of Branched Homoallyl Amines. *Angew. Chem., Int. Ed.* **2016**, *55*, 1102. (d) Yeung, K.; Ruscoe, R. E.; Rae, J.; Pulis, A. P.; Procter, D. J. Enantioselective Generation of Adjacent Stereocenters in a Copper-

Catalyzed Three-Component Coupling of Imines, Allenes, and Diboranes. *Angew. Chem., Int. Ed.* **2016**, *55*, 11912. (e) Jang, H.; Romiti, F.; Torker, S.; Hoveyda, A. H. Catalytic diastereo- and enantioselective additions of versatile allyl groups to N−H ketimines. *Nat. Chem.* **2017**, *9*, 1269. (f) Deng, H.; Meng, Z.; Wang, S.; Zhang, Z.; Zhang, Y.; Shangguan, Y.; Yang, F.; Yuan, D.; Guo, H.; Zhang, C. Enantioselective Copper-Catalyzed Three-Component Carboboronation of Allenes: Access to Functionalized Dibenzo [*b,f*][1,4]oxazepine Derivatives. *Adv. Synth. Catal.* **2019**, *361*, 3582. (g) Yeung, K.; Talbot, F. J. T.; Howell, G. P.; Pulis, A. P.; Procter, D. J. Copper-Catalyzed Borylative Multicomponent Synthesis of Quaternary α-Amino Esters. *ACS Catal.* **2019**, *9*, 1655. (h) Zhao, C.-Y.; Zheng, H.; Ji, D.-W.; Min, X.-T.; Hu, Y.-C.; Chen, Q.-A. Copper-Catalyzed Asymmetric Carboboronation of Allenes to Access α-Quaternary Amino Esters with Adjacent Stereocenters. *Cell Reports Physical Science* **2020**, *1*, 100067. (i) Zhang, S.; del Pozo, J.; Romiti, F.; Mu, Y.; Torker, S.; Hoveyda, A. H. Delayed catalyst function enables direct enantioselective conversion of nitriles to NH_2-amines. *Science* **2019**, *364*, 45.

(4) (a) Meng, F.; McGrath, K. P.; Hoveyda, A. H. Multifunctional organoboron compounds for scalable natural product synthesis. *Nature* **2014**, *513*, 367. (b) Semba, K.; Bessho, N.; Fujihara, T.; Terao, J.; Tsuji, Y. Copper-Catalyzed Borylative Allyl-Allyl Coupling Reaction. *Angew. Chem., Int. Ed.* **2014**, *53*, 9007. (c) Xu, G.; Fu, B.; Zhao, H.; Li, Y.; Zhang, G.; Wang, Y.; Xiong, T.; Zhang, Q. Enantioselective and site-specific copper-catalyzed reductive allyl-allyl cross-coupling of allenes. *Chem. Sci.* **2019**, *10*, 1802.

(5) Zhou, Y.; You, W.; Smith, K. B.; Brown, M. K. Copper-Catalyzed Cross-Coupling of Boronic Esters with Aryl Iodides and Application to the Carboboration of Alkynes and Allenes. *Angew. Chem., Int. Ed.* **2014**, *53*, 3475.

(6) (a) Meng, F.; Li, X.; Torker, S.; Shi, Y.; Shen, X.; Hoveyda, A. H. Catalytic enantioselective 1,6-conjugate additions of propargyl and allyl groups. *Nature* **2016**, *537*, 387. (b) Huang, Y.; Torker, S.; Li, X.; del Pozo, J.; Hoveyda, A. H. Racemic Vinylallenesin Catalytic Enantioselective Multicomponent Processes: Rapid Generation of Complexity through 1,6-Conjugate Additions. *Angew. Chem., Int. Ed.* **2019**, *58*, 2685.

(7) (a) Fujihara, T.; Sawada, A.; Yamaguchi, T.; Tani, Y.; Terao, J.; Tsuji, Y. Boraformylation and Silaformylation of Allenes. *Angew. Chem., Int. Ed.* **2017**, *56*, 1539. (b) Boreux, A.; Indukuri, K.; Gagosz, F.; Riant, O. Acyl Fluorides as Efficient Electrophiles for the Copper-Catalyzed Boroacylation of Allenes. *ACS Catal.* **2017**, *7*, 8200. (c) Sawada, A.; Fujihara, T.; Tsuji, Y. Copper-Catalyzed Bora-Acylation and Bora-Alkoxyoxalylation of Allenes. *Adv. Synth. Catal.* **2018**, *360*, 2621. (d) Han, J.; Zhou, W.; Zhang, P.-C.; Wang, H.; Zhang, R.; Wu, H.-H.; Zhang, J. Design and Synthesis of WJ-Phos, and Application in Cu-Catalyzed Enantioselective Boroacylation of 1,1-Disubstituted Allenes. *ACS Catal.* **2019**, *9*, 6890.

(8) Gong, T.-J.; Yu, S.-H.; Li, K.; Su, W.; Lu, X.; Xiao, B.; Fu, Y. Copper-Catalyzed Alkynylboration of Alkenes with Diboron Reagents and Bromoalkynes. *Chem. - Asian J.* **2017**, *12*, 2884.

(9) (a) Kageyuki, I.; Osaka, I.; Takaki, K.; Yoshida, H. Copper-Catalyzed B(dan)-Installing Carboboration of Alkenes. *Org. Lett.* **2017**, *19*, 830. (b) Ozawa, Y.; Iwamoto, H.; Ito, H. Copper(I)-catalysed regio- and diastereoselective intramolecular alkylboration of terminal allenes via allylcopper(I) isomerization. *Chem. Commun.* **2018**, *54*, 4991.

(10) For 1,4-addition of β-borylated allylcopper intermediates, see: (a) Li, X.; Meng, F.; Torker, S.; Shi, Y.; Hoveyda, A. H. Catalytic Enantioselective Conjugate Additions of (pin)B-Substituted Allylcopper Compounds Generated in situ from Butadiene or Isoprene. *Angew. Chem., Int. Ed.* **2016**, *55*, 9997. For other recent copper-catalyzed borylative conjugate addition reactions, see: (b) Kim-Lee, S.-H.; Alonso, I.; Mauleón, P.; Arrayás, R. G.; Carretero, J. C. Rationalizing the Role of NaO*t*Bu in Copper-Catalyzed Carboboration of Alkynes: Assembly of Allylic All-Carbon Quaternary Stereocenters. *ACS Catal.* **2018**, *8*, 8993. (c) He, C.-Y.; Li, Q.-H.; Wang, X.; Wang, F.; Tian, P.; Lin, G.-Q. Copper-Catalyzed Asymmetric Borylative Cyclization of Cyclohexadienone-Containing 1,6-Dienes. *Adv. Synth. Catal.* **2020**, *362*, 765.

(11) For selected transition-metal-catalyzed cascade reactions of cyclohexadienone-tethered allene (1,6-enallene) substrates, see: (a) He, Z.-T.; Tang, X.-Q.; Xie, L.-B.; Cheng, M.; Tian, P.; Lin, G.-Q. Efficient Access to Bicyclo[4.3.0]nonanes: Copper-Catalyzed Asymmetric Silylative Cyclization of Cyclohexadienone-Tethered Allenes. *Angew. Chem., Int. Ed.* **2015**, *54*, 14815. (b) Tan, Y.-X.; Tang, X.-Q.; Liu, P.; Kong, D.-S.; Chen, Y.-L.; Tian, P.; Lin, G.-Q. CuH-Catalyzed Asymmetric Intramolecular Reductive Coupling of Allenes to Enones. *Org. Lett.* **2018**, *20*, 248. (c) Nguyen, T. L. N.; Incerti-Pradillos, C. A.; Lewis, W.; Lam, H. W. Enantioselective nickel-catalyzed arylative intramolecular 1,4-allylations. *Chem. Commun.* **2018**, *54*, 5622. (d) Kong, D.-S.; Wang, Y.-F.; Tan, Y.-X.; Zhang, J.-L.; Zhang, J.-G.; Tian, P.; Lin, G.-Q. Trisannulation of benzamides and cyclohexadienone-tethered 1,1-disubstituted allenes initiated by Cp*Rh(III)-catalyzed C−H activation. *Org. Chem. Front.* **2019**, *6*, 699.

(12) The conjugate borylation to 4,4-dimethyl-2-cyclohexenone was inhibited; see: Feng, X.; Yun, J. Catalytic enantioselective boron conjugate addition to cyclic carbonyl compounds: a new approach to cyclic β-hydroxy carbonyls. *Chem. Commun.* **2009**, *43*, 6577.

(13) Semba, K.; Fujihara, T.; Terao, J.; Tsuji, Y. Copper-Catalyzed Borylation of α-Alkoxy Allenes with Bis(pinacolato)diboron: Efficient Synthesis of 2-Boryl 1,3-Butadienes. *Angew. Chem., Int. Ed.* **2013**, *52*, 12400.

(14) For details on more chiral ligand screening, see the Supporting Information.

(15) Selected examples on conjugate borylation: (a) Lee, J.-E.; Yun, J. Catalytic Asymmetric Boration of Acyclic α,β-Unsaturated Esters and Nitriles. *Angew. Chem., Int. Ed.* **2008**, *47*, 145. (b) Chen, I.-H.; Yin, L.; Itano, W.; Kanai, M.; Shibasaki, M. Catalytic Asymmetric Synthesis of Chiral Tertiary Organoboronic Esters through Conjugate Boration of β-Substituted Cyclic Enones. *J. Am. Chem. Soc.* **2009**, *131*, 11664. (c) O'Brien, J. M.; Lee, K.-S.; Hoveyda, A. H. Enantioselective Synthesis of Boron-Substituted Quaternary Carbons by NHC−Cu-Catalyzed Boronate Conjugate Additions to Unsaturated Carboxylic Esters, Ketones, or Thioesters. *J. Am. Chem. Soc.* **2010**, *132*, 10630. (d) Moure, A. L.; Arrayás, R. G.; Carretero, J. C. Catalytic asymmetric conjugate boration of α,β-unsaturated sulfones. *Chem. Commun.* **2011**, *47*, 6701. (e) Kobayashi, S.; Xu, P.; Endo, T.; Ueno, M.; Kitanosono, T. Chiral Copper(II)-Catalyzed Enantioselective Boron Conjugate Additions to α,β-Unsaturated Carbonyl Compounds in Water. *Angew. Chem., Int. Ed.* **2012**, *51*, 12763. (f) He, Z.-T.; Zhao, Y.-S.; Tian, P.; Wang, C.-C.; Dong, H.-Q.; Lin, G.-Q. Copper-Catalyzed Asymmetric Hydroboration of α-Dehydroamino Acid Derivatives: Facile Synthesis of Chiral β-Hydroxy-α-amino Acids. *Org. Lett.* **2014**, *16*, 1426.

(16) Liu, P.; Fukui, Y.; Tian, P.; He, Z.-T.; Sun, C.-Y.; Wu, N.-Y.; Lin, G.-Q. Cu-Catalyzed Asymmetric Borylative Cyclization of Cyclohexadienone-Containing 1,6-Enynes. *J. Am. Chem. Soc.* **2013**, *135*, 11700.

(17) Li, Q.-H.; Gao, D.; He, C.-Y.; Liao, Q.; Tan, Y.-X.; Wang, Y.-H.; Ding, R.; Lin, G.-Q.; Tian, P. One-Pot Preparation of Bridged Tricyclic and Fused Tetracyclic Scaffolds via Rhodium(III)-Catalyzed Asymmetric Borylative Cyclization. *Cell Reports Physical Science* **2020**, *1*, 100222.