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Ir-catalyzed reductive amination and transfer hydrogenation of diketones: access to β- and γ-amino alcohols†

Jinghui Tong,[a] Shilin Guo,[a] Huajie Zhu,[a] Lu Ouyang,[a] Jianhua Liao *[a] and Youchun Li*[b]

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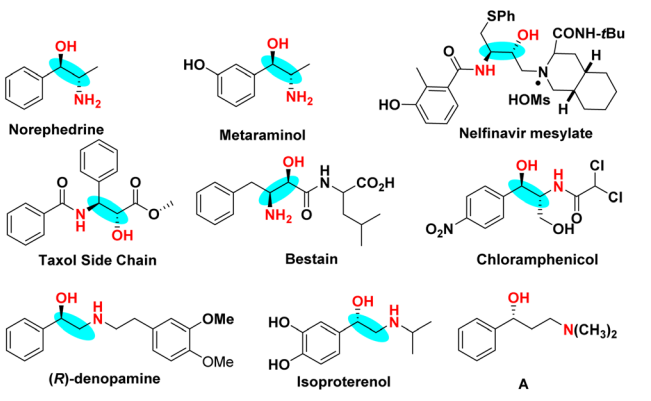
β- and γ-Amino alcohols are among the most significant structural motifs in pharmacologically active molecules and pharmaceuticals. Herein, a protocol for the construction of β- and γ-amino alcohols *via* reductive amination and transfer hydrogenation of diketones with aromatic amines is described. This reaction is performed by utilizing iridium complexes as catalysts and HCO_2H as a hydrogen donor to deliver a library of β- and γ-amino alcohols under mild and operationally simple conditions. Successful scale-up performance was also conducted under standard conditions.

β- and γ-Amino alcohol backbones are extensively found in pharmacologically active molecules and pharmaceutical compounds. Amino alcohols also serve as key intermediates of various pharmacophores in medicine, cosmetics, materials science, organic synthesis and medicinal chemistry.[1] For instance, metaraminol is frequently employed as a rescue drug in patients with shock, chloramphenicol shows potent antibacterial activity against Gram-negative bacteria, and indinavir and adrenaline are used to treat HIV-1 infections in adults and children (Scheme 1).[2] Amino alcohols also serve as ligands in the field of catalytic organic synthesis.[3] Therefore, it is of great significance to develop a new universal, atomic and step-economical strategy for the synthesis of amino alcohols in the rapid development of innovative drugs.[4]

Ring-opening aminolysis of epoxides represents one of the classical strategies for constructing β-amino alcohols. Scandium,[5] niobium,[6] gadolinium,[7] chromium,[8] and organic molecules[9] are employed as catalysts for the construction of β-amino alcohols. In addition, the Ru-catalyzed hydrogenation of α-amino ketones constitute an alternative effective strategy for β-amino alcohol synthesis.[10] In 2019, Zhong's group reported a highly efficient Rh-catalyzed hydroxylation of alkenes to access β-amino alcohol compounds.[11] In addition, the radical domino reaction[12] and *N*-alkylation of amines with alcohols[13] were employed for β-amino alcohol synthesis.

The hydrogenation of β-amino ketones[14] could also be employed for γ-amino alcohol synthesis.[15] In 2015, Zhang's group successfully reported the ruthenium complex-catalyzed hydrogenation of β-amino ketones to produce γ-amino alcohols.[16] Furthermore, the hydroamination of allyl ketones[17] and alcohols,[18] ring-opening of epoxides with amines,[2] oxidative amination of alkenes,[19] addition or reduction of amino aldehydes or ketones,[20] addition of an amino-carbon anion to a carbonyl compound,[21] and the amine-allylation of alcohols[22] were utilized as effective strategies for the formation of γ-amino alcohols. Although many encouraging achievements have been made in the synthesis of chiral β- and γ-amino alcohols, there are still some deficiencies in the substrate scope. Therefore, employing the easily accessible materials as substrates is still highly desirable for the production of β- and γ-amino alcohols.

In recent years, we have studied transfer hydrogenation reactions using *N*,*N*-iridium complexes as catalysts.[23] Recently, Kuwata *et al.* developed an efficient asymmetric reductive amination of α-keto acids to access α-amino acids catalyzed by



Scheme 1 β- and γ-Amino alcohol motifs existing in biologically active molecules.

[a]*School of Pharmacy, Gannan Medical University, Ganzhou 341000, Jiangxi Province, P. R. China. E-mail: liaojianhua715@163.com*

[b]*The Affiliated Ganzhou Hospital, Jiangxi Medical College, Nanchang University, Ganzhou 341000, Jiangxi Province, P. R. China*

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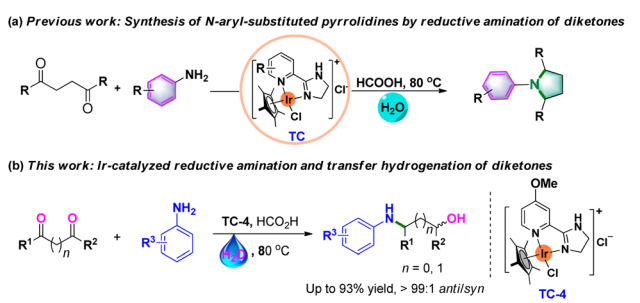
Cp*Ir catalysts bearing a chiral *N*-(2-picolyl)sulfonamidato ligand.[24] Very recently, we also reported the protocol for *N*-aryl-substituted pyrrolidine synthesis *via* Ir-catalyzed successive reductive amination of diketones (Scheme 2a).[25] Based on the successful formation of five-membered pyrrolidines with 2,5-diketones as substrates, the construction of four-membered or even the three-membered heterocyclic ring was also designed using 2,4-diketones or 2,3-diketones as substrates. However, this only produced β- and γ-amino alcohols, and no desired cyclic products were formed under standard conditions. Herein, we report on an Ir-catalyzed reductive amination and transfer hydrogenation of 2,4-diketones or 2,3-diketones to access β- and γ-amino alcohols (Scheme 2b). Various 2,4-diketones or 2,3-diketones and aromatic amines could be employed as substrates in this catalytic system, delivering the desired amino alcohols in moderate to excellent yields. This Ir-catalyzed reductive amination and transfer hydrogenation process offers an alternative protocol for β-and γ-amino alcohol synthesis.

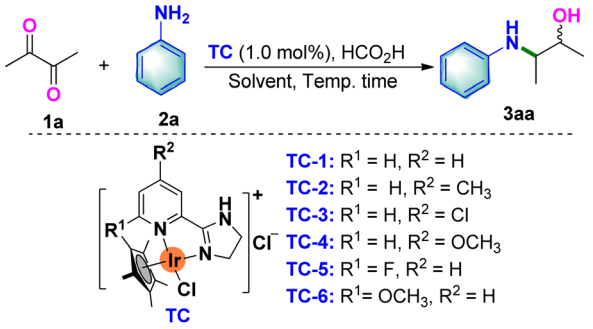
We initiated our attempts at this Ir-catalyzed reductive amination and transfer hydrogenation of 2,3-butanedione (**1a**) with aniline (**2a**) as model substrates (Table 1). Preliminary reaction condition screens with **TC-1–TC-6** as catalysts and 20.0 equivalent of HCO_2H as the hydrogen donor in the presence of toluene afforded the β-amino alcohol **3aa** in low yields (Table 1, entries 1–6). Based on our previous work[21,22] showing that the reaction media would enhance the solubility of iridium complexes, we then investigated the influence of solvents (Table 1, entries 7–12). As anticipated, an increased yield of 80% was attained in the presence of H_2O (Table 1, entry 12). To afford the optimal conditions, different quantities of HCO_2H and other reaction times were further explored (Table 1, entries 13–19). Indeed, increasing the loading of HCO_2H and prolonging the reaction time furnished the best yield of 93% (Table 1, entry 19). Decreasing the reaction temperature showed reduced performance (Table 1, entries 20–22). Control studies confirmed the necessity of the iridium complex and HCO_2H for this reductive amination and transfer hydrogenation transformation (Table 1, entries 23 and 24).

With the optimized reaction conditions in hand, we next probed the generality of the substrate scope. As showed in Table 2, 2,3-butanedione (**1a**) was capable of reductive amination with electron-withdrawing and electron-donating *para*-substituted aromatic amines (**2b–2f**) and transfer hydrogenation under standard conditions, furnishing the β-amino alcohol products



Scheme 2 Ir-catalyzed difunctionalization of diketones.

Table 1 Optimization of the reaction conditions[a]

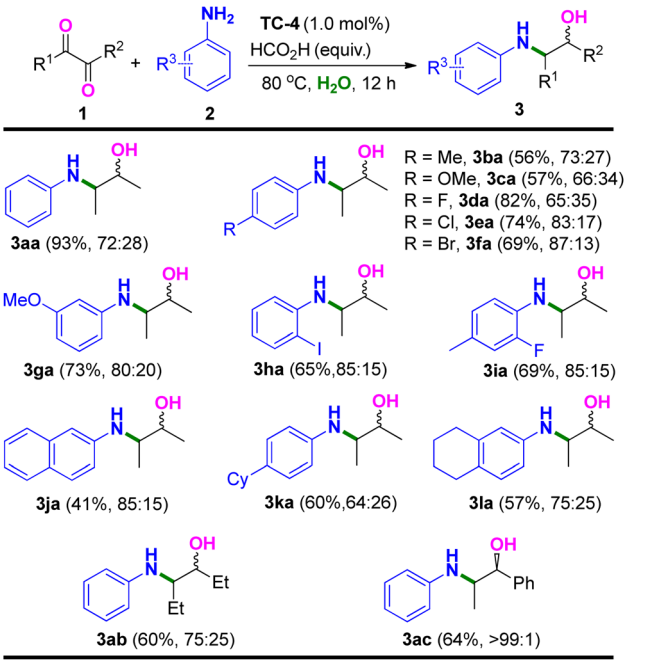


Entry	Catalyst	Solvent	T (°C)	HCO_2H (equiv.)	Time (h)	Yield[b] (%)
1	**TC-1**	Toluene	80	20	6	10
2	**TC-2**	Toluene	80	20	6	11
3	**TC-3**	Toluene	80	20	6	3
4	**TC-4**	Toluene	80	20	6	15
5	**TC-5**	Toluene	80	20	6	14
6	**TC-6**	Toluene	80	20	6	4
7	**TC-4**	DMF	80	20	6	27
8	**TC-4**	1,4-Dioxane	80	20	6	n.d.
9	**TC-4**	THF	80	20	6	n.d
10	**TC-4**	MeOH	80	20	6	54
11	**TC-4**	Acetone	80	20	6	n.d
12	**TC-4**	H_2O	80	20	6	80
13	**TC-4**	H_2O	80	5	6	45
14	**TC-4**	H_2O	80	10	6	54
15	**TC-4**	H_2O	80	15	6	72
16	**TC-4**	H_2O	80	25	6	83
17	**TC-4**	H_2O	80	30	6	83
18	**TC-4**	H_2O	80	25	9	90
19	**TC-4**	**H_2O**	**80**	**25**	**12**	**99 (93%)[c]**
20	**TC-4**	H_2O	rt	25	12	87
21	**TC-4**	H_2O	60	25	12	97
22	**TC-4**	H_2O	100	25	12	99
23	—	H_2O	80	25	12	—
24	**TC-4**	H_2O	80	—	12	—

[a] Reaction conditions: a mixture of **1a** (0.5 mmol, 1.0 equiv.), **2a** (0.6 mmol, 1.1 equiv.), **TC** catalyst (1.0 mol%), HCO_2H, and solvent (2.0 mL) was sealed in a 25.0 mL Schlenk tube under air. [b] Yield was determined by NMR with dimethyl terephthalate as internal standard. [c] Parenthesis is isolated yield based on **1a**.

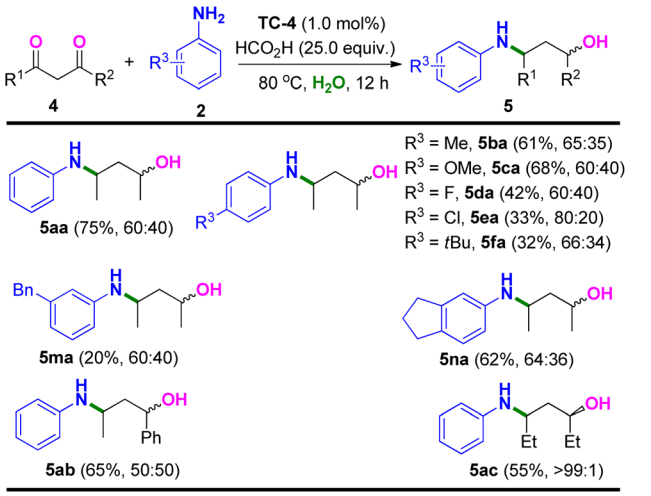
3ba–3fa in moderate yields and stereoselectivities. *Meta*-, *ortho*-, and *di*-substituted aromatic amines (**2g–2i**) also participated, producing the corresponding β-amino alcohols **3ga–3ia** in similar moderate yields and stereoselectivities. Large block amines such as naphthylamine (**2j**), 4-cyclohexyl aniline (**2k**), and 5,6,7,8-tetrahydronaphthalen-2-amine (**2l**) were also tolerated in this catalytic system, providing the desirable reductive amination and transfer hydrogenation products of **3ja–3la.** On the other hand, the more steric hindrance of 2,3-hexanedione (**1b**) gave same moderate yield and stereoselectivity of the corresponding product (**3ab**). Interestingly, aromatic diketone of 1-phenylpropane-1,2-dione (**1c**) was also a successful substrate, and showed improved stereoselectivity (*anti*/*syn* > 99 : 1) and excellent regioselectivity.

Table 2 Substrate scope of the Ir-catalyzed reductive amination and transfer hydrogenation of 2,3-diketones with aromatic amines[a,b,c]

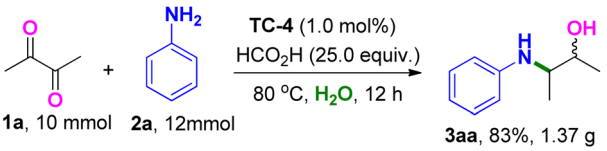


[a] Reaction conditions: a mixture of **1** (0.5 mmol, 1.0 equiv.), **2** (0.6 mmol, 1.1 equiv.), **TC-4** (1.0 mol%), HCO_2H (12.5 mmol, 25.0 equiv.), and H_2O (2.0 mL) were sealed in a 25.0 mL Schlenk tube under air at 80 °C for 12 h. [b] Isolated yield based on **1**. [c] The value of the *anti*/*syn* ratio.

Table 3 Substrate scope of Ir-catalyzed reductive amination and transfer hydrogenation of 2,4-diketones with aromatic amines[a,b,c]



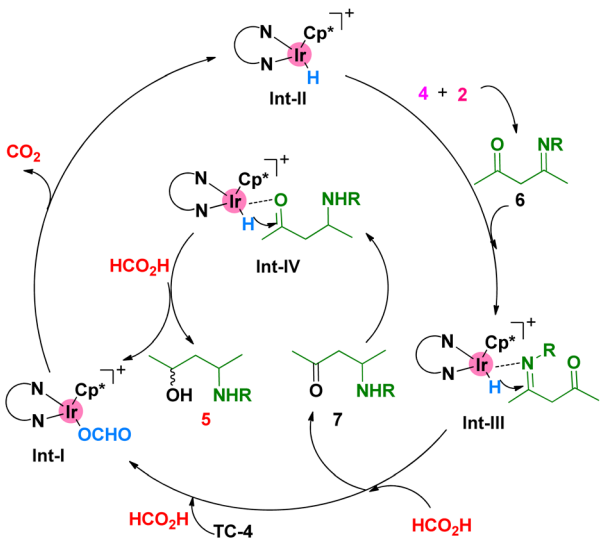
[a] Reaction conditions: a mixture of **4** (0.5 mmol, 1.0 equiv.), **2** (0.6 mmol, 1.1 equiv.), **TC-4** (1.0 mol%), HCO_2H (12.5 mmol, 25.0 equiv.), and H_2O (2.0 mL) were sealed in a 25.0 mL Schlenk tube under air at 80 °C for 12 h. [b] Isolated yield based on **4**. [c] The value of the *anti*/*syn* ratio.



Scheme 3 Large-scale synthesis of **3aa**.

We next investigated the substrate scope with respect to the 1,3-diketones with aromatic amines (Table 3). The γ-amino alcohol of 4-(phenylamino)pentan-2-ol could also be prepared through this method (75% yield) using pentane-2,4-dione (**4a**) as the substrate. Moreover, *para*-substituted aromatic amines (**2b–2f**) could also be used in the reaction. However, products of **5da–5fa** were formed in lower yields (32–42%) when the *para*-substituted aromatic amines bearing electron-withdrawing groups were used (**2d–2f**). A low yield was also observed for a *meta*-benzyl substituted aniline (**2m**). Pleasingly, 62% yield and moderate stereoselectivity of reductive amination and transfer hydrogenation product **5na** were provided when 2,3-dihydro-1*H*-inden-5-amine (**2n**) was used in this reaction. Other aromatic and sterically more hindered diketones were also tolerated to produce **5ab** and **5ac** in moderate yields and excellent stereoselectivity (>99 : 1).

The robustness of this Ir-catalyzed reductive amination and transfer hydrogenation transformation was documented by performing the model reaction on a larger scale. As showcased in Scheme 3, 1.37 g of the product **3aa** was afforded in 83% yield when 2,3-butanedione (**1a**) was loaded at a 10.0 mmol scale under standard conditions. With this successful large-scale performance, the follow-up asymmetric studies using chiral iridium complexes are underway and will be reported soon. In addition, the asymmetric Ir-catalyzed reduction amination of ketones with the model reaction was investigated under the optimized conditions (Scheme S1, ESI†). The desired reductive product **3aa** was obtained using the chiral iridium complexes **C1–C6** as catalysts, while a low enantioselectivity of the product



Scheme 4 Proposed mechanism.

was observed. The design and synthesis of more chiral iridium complexes are underway, and will be further applied in the asymmetric synthesis.

The proposed catalytic cycle of this Ir-catalyzed reductive amination and transfer hydrogenation is showcased in Scheme 4. On the one hand, the active Ir–H intermediate of **Int-II** was formed under the conditions of the iridium complex and HCO_2H. On the other hand, the intermediate of imidone **6** was generated, which was subsequently reduced by **Int-II** to form the amino ketone **7**. A more similar reduction of carbonyl by the active Ir–H was performed to furnish the desired product **5** and finish the catalytic cycle. Of note, it is possible that the transfer hydrogenation of the carbonyl group took place first, followed by the reductive amination process.

Conclusions

In summary, we report the reductive amination and transfer hydrogenation of diketones enabled by iridium complexes, facilitating access to diverse β- and γ-amino alcohols in moderate yields and stereoselectivities. The 2,3-diketones, 2,4-diketones and various substituted aromatic amines could be successfully employed in this system. The synthetic potential of this protocol was solidified by the large-scale performance.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

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Notes and references

1 P. Juszczyk, R. Kasprzykowska and A. S. Kołodziejczyk, Simple and efficient synthesis of chiral amino alcohols with an amino acid-based skeleton, *Lett. Pept. Sci.*, 2003, **10**, 79.

2 J. L. Schwarz, R. Kleinmans, T. Paulisch and F. Glorius, 1,2-Amino alcohols *via* Cr/photoredox Dual-Catalyzed Addition of α-Amino Carbanion Equivalents to Carbonyls, *J. Am. Chem. Soc.*, 2020, **142**, 2168.

3 (*a*) M. T. Reetz, M. W. Drewes and A. Schmitz, Stereoselective synthesis of β-amino alcohols from optically active α-amino acids, *Angew. Chem., Int. Ed.*, 1987, **26**, 1141; (*b*) M. C. Wang, Z. K. Liu, S. Li, X. Ding, Y. Li and M. S. Tang, An experimental and theoretical study on free ligand conformational preferences and enantioselectivity relationship for the asymmetric addition of diethylzinc to benzaldehyde, *Tetrahedron: Asymmetry*, 2010, **21**, 486.

4 (*a*) C. E. O'Connell, K. A. Salvato, Z. Meng, B. A. Littlefield and C. E. Schwartz, Synthesis and evaluation of hapalosin and analogs as MDR-reversing agents, *Bioorg. Med. Chem. Lett.*, 1999, **9**, 1541; (*b*) S. C. Bergmeier and D. M. Stanchina, Acylnitrene route to vicinal amino alcohols. Application to the synthesis of (−)-bestatin and analogues, *J. Org. Chem.*, 1999, **64**, 2852; (*c*) A. W. He and J. G. Cory, p^{53}-independent anisomycin induced G1 arrest and apoptosis in L1210 cell lines, *Anticancer Res.*, 1999, **19**, 421; (*d*) J. B. H. Tok and R. R. Rando, Simple aminols as aminoglycoside surrogates, *J. Am. Chem. Soc.*, 1998, **120**, 8279; (*e*) B. D. Feske, Bestatin: three decades of synthetic strategies, *Curr. Org. Chem.*, 2007, **11**, 483; (*f*) J. P. Michael, Indolizidine and quinolizidine alkaloids, *Nat. Prod. Rep.*, 2008, **25**, 139.

5 E. Mai and C. Schneider, Scandium-bipyridine-catalyzed enantioselective aminolysis of meso-epoxides, *Chem.–Eur. J.*, 2007, **13**, 2729.

6 K. Arai, M. Salter, Y. Yamashita and S. Kobayashi, Enantioselective desymmetrization of meso epoxides with anilines catalyzed by a niobium complex of a chiral multidentate binol derivative, *Angew. Chem., Int. Ed.*, 2007, **46**, 955.

7 C. Wang and H. Yamamoto, Gadolinium-catalyzed regio-and enantioselective aminolysis of aromatic trans-2,3-epoxy sulfonamides, *Angew. Chem., Int. Ed.*, 2015, **54**, 8760.

8 R. Tak, M. Kumar, T. Menapara, M. K. Choudhary, R. I. Kureshy and N. U. H. Khan, Asymmetric catalytic syntheses of pharmaceutically important β-amino-α-hydroxyl esters by enantioselective aminolysis of methyl phenylglycidate, *ChemCatChem*, 2017, **9**, 322.

9 M. Kumar, R. I. Kureshy, S. Saravanan, S. Verma, A. Jakhar, N. U. H. Khan and H. C. Bajaj, Unravelling a new class of chiral organocatalyst for asymmetric ring-opening reaction of meso epoxides with anilines, *Org. Lett.*, 2014, **16**, 2798.

10 J. H. Xie, S. Liu, W. L. Kong, W. J. Bai, X. C. Wang, L. X. Wang and Q. L. Zhou, Highly enantioselective and diastereoselective synthesis of chiral amino alcohols by ruthenium-catalyzed asymmetric hydrogenation of α-amino aliphatic ketones, *J. Am. Chem. Soc.*, 2009, **131**, 4222.

11 Y. Shi, Y. Wang, X. Lu, Y. Zhang, Y. Wu and F. Zhong, Rhodium-catalyzed aminohydroxylation of unactivated alkenes in aqueous media for the benign synthesis of 1, 2-amino alcohols, *Green Chem.*, 2019, **21**, 780.

12 R. Spaccini, A. Ghilardi, N. Pastori, A. Clerici, C. Puna and O. Porta, Efficient radical domino approach to β-aminoalcohols from arylamines and alcohols triggered by Ti (III)/t-BuOOH, *Tetrahedron*, 2010, **66**, 2044.

13 C. Wang, C. Chen, J. Han, J. Zhang, Y. Yao and Y. Zhao, Insight into O_2-promoted base-catalyzed *N*-alkylation of amines with alcohols, *Eur. J. Org Chem.*, 2015, **2015**, 2972–2977.

14 (*a*) S. Sakuraba and K. Achiwa, Practical asymmetric synthesis of (*R*)-Fluoxetine hydrochloride catalyzed by (2*S*,4*S*)-4-dicyclohexylphosphino-2-diphenylphos-

phinomethyl-1-(*N*-methyl carbamoyl) pyrrolidine-Rhodium complex1, *Synlett*, 1991, **1991**, 689; (*b*) S. Sakuraba and K. Achiwa, Efficient asymmetric hydrogenation of β-and γ-amino ketone derivatives leading to practical synthesis of fluoxetine and eprozinol, *Chem. Pharm. Bull.*, 1995, **43**, 748; (*c*) D. Liu, W. Gao, C. Wang and X. Zhang, Practical synthesis of enantiopure γ-amino alcohols by rhodium-catalyzed asymmetric hydrogenation of β-secondary-amino ketones, *Angew. Chem., Int. Ed.*, 2005, **117**, 1715; (*d*) H. Geng, X. Zhang, M. Chang, L. Zhou, W. Wu and X. Zhang, Ruthenium-catalyzed asymmetric hydrogenation of β-keto-enamines: An efficient approach to chiral γ-amino alcohols, *Adv. Synth. Catal.*, 2011, **353**, 3039; (*e*) J. Wang, D. Liu, Y. Liu and W. Zhang, Asymmetric hydrogenation of β-amino ketones with the bimetallic complex RuPHOX-Ru as the chiral catalyst, *Org. Biomol. Chem.*, 2013, **11**, 3855.

15 (*a*) J. N. Zhou, Q. Fang, Y. H. Hu, L. Y. Yang, F. F. Wu, L. J. Xie and S. Li, Copper (II)-catalyzed enantioselective hydrosilylation of halo-substituted alkyl aryl and heteroaryl ketones: asymmetric synthesis of (*R*)-fluoxetine and (*S*)-duloxetine, *Org. Biomol. Chem.*, 2014, **12**, 1009; (*b*) A. Träff, R. Lihammar and J. E. Bäckvall, A chemoenzymatic dynamic kinetic resolution approach to enantiomerically pure (*R*)-and (*S*)-duloxetine, *J. Org. Chem.*, 2011, **76**, 3917; (*c*) Y. Gao and K. B. Sharpless, Asymmetric synthesis of both enantiomers of tomoxetine and fluoxetine. Selective reduction of 2, 3-epoxycinnamyl alcohol with Red-Al, *J. Org. Chem.*, 1988, **53**, 4081; (*d*) H. Kakei, T. Nemoto, T. Ohshima and M. Shibasaki, Efficient synthesis of chiral α-and β-hydroxy amides: Application to the synthesis of (*R*)-Fluoxetine, *Angew. Chem., Int. Ed.*, 2004, **43**, 317; (*e*) Y. Fujima, M. Ikunaka, T. Inoue and J. Matsumoto, Synthesis of (*S*)-3-(*N*-Methylamino)-1-(2-thienyl) propan-1-ol: revisiting Eli Lilly's resolution-racemization-recycle synthesis of duloxetine for its robust processes, *Org. Process Res. Dev.*, 2006, **10**, 905; (*f*) D. W. Robertson, J. H. Krushinski, R. W. Fuller and J. D. Leander, The absolute configurations and pharmacological activities of the optical isomers of fluoxetine, a selective serotonin-uptake inhibitor, *J. Med. Chem.*, 1988, **31**, 1412.

16 J. Wang, Y. Wang, D. Liu and W. Zhang, Asymmetric hydrogenation of β-secondary amino ketones catalyzed by a ruthenocenyl phosphino-oxazoline-ruthenium complex (RuPHOX-Ru): the Synthesis of γ-secondary amino alcohols, *Adv. Synth. Catal.*, 2015, **357**, 3262.

17 L. Wu, R. Jin, L. Li, X. Hu, T. Cheng and G. Liu, A Michael addition-asymmetric transfer hydrogenation one-pot enantioselective tandem process for syntheses of chiral γ-secondary amino alcohols, *Org. Lett.*, 2017, **19**, 3047.

18 F. Li, L. Long, Y. M. He, Z. Li, H. Chen and Q. H. Fan, Manganese-catalyzed asymmetric formal hydroamination of allylic alcohols: A remarkable macrocyclic ligand effect, *Angew. Chem., Int. Ed.*, 2022, **134**, e202202972.

19 T. J. Donohoe, C. K. Callens, A. Flores, A. R. Lacy and A. H. Rathi, Recent developments in methodology for the direct oxyamination of olefins, *Chem.–Eur. J.*, 2011, **17**, 58.

20 O. K. Karjalainen and A. M. P. Koskinen, Diastereoselective synthesis of vicinal amino alcohols, *Org. Biomol. Chem.*, 2012, **10**, 4311.

21 K. Li, X. Shao, L. Tseng and S. J. Malcolmson, 2-Azadienes as reagents for preparing chiral amines: Synthesis of 1,2-amino tertiary alcohols by Cu-catalyzed enantioselective reductive couplings with ketones, *J. Am. Chem. Soc.*, 2018, **140**, 598.

22 K. Spielmann, M. Xiang, L. A. Schwartz and M. J. Krische, Direct conversion of primary alcohols to 1,2-amino alcohols: Enantioselective Iridium-catalyzed carbonyl reductive coupling of phthalimido-allene *via* hydrogen auto-transfer, *J. Am. Chem. Soc.*, 2019, **141**, 14136.

23 (*a*) L. Ouyang, Y. Liang, S. Wang, J. Liao and R. Luo, Access of arylmethanes *via* iridium-catalyzed deoxygenative cross-coupling of aryl ketones with anilines/phenols, *J. Catal.*, 2024, **433**, 115492; (*b*) R. Luo, S. Wang, Y. Liang, J. Tong, J. Liao and L. Ouyang, Ir-catalyzed selective reductive *N*-formylation and transfer hydrogenation of *N*-heteroarenes, *Organometallics*, 2024, **43**, 2097; (*c*) L. Ouyang, R. Miao, Z. Yang and R. Luo, Iridium-catalyzed reductive amination of carboxylic acids, *J. Catal.*, 2023, **418**, 283; (*d*) Y. Wei, Y. Liang, R. Luo and L. Ouyang, Recent advances of Cp*Ir complexes for transfer hydrogenation: focus on formic acid/formate as hydrogen donors, *Org. Biomol. Chem.*, 2023, **21**, 7484; (*e*) Y. Xia, S. Wang, R. Miao, J. Liao, L. Ouyang and R. Luo, Synthesis of *N*-alkoxy amines and hydroxylamines *via* the Iridium-catalyzed transfer hydrogenation of oximes, *Org. Biomol. Chem.*, 2022, **20**, 6394; (*f*) L. Ouyang, Y. Xia, R. Miao, J. Liao and R. Luo, Iridium-catalyzed reductive etherification of α,β-unsaturated ketones and aldehydes with alcohols, *Org. Biomol. Chem.*, 2022, **20**, 2621; (*g*) N. Luo, Y. Zhong, H. Shui and R. Luo, pH-Mediated selective synthesis of *N*-allylic alkylation or *N*-alkylation amines with allylic alcohols *via* an Iridium catalyst in water, *J. Org. Chem.*, 2021, **86**, 15509; (*h*) H. Wen, N. Luo, Q. Zhu and R. Luo, Amide iridium complexes as catalysts for transfer hydrogenation reduction of *N*-sulfonylimine, *J. Org. Chem.*, 2021, **86**(5), 3850.

24 T. Yajima, A. Katayama, T. Ito, T. Kawada, K. Yabushita, T. Yasuda, T. Ohta, T. Katayama, N. Utsumi, Y. Kayaki and S. Kuwata, Asymmetric reductive amination of α-keto acids using Ir-based hydrogen transfer catalysts: An access to unprotected unnatural α-amino acids, *Org. Lett.*, 2024, **26**, 1426.

25 J. Liao, J. Tong, L. Liu, L. Ouyang and R. Luo, Construction of N-aryl-substituted pyrrolidines by successive reductive amination of diketones *via* transfer hydrogenation, *Molecules*, 2024, **29**, 2565.