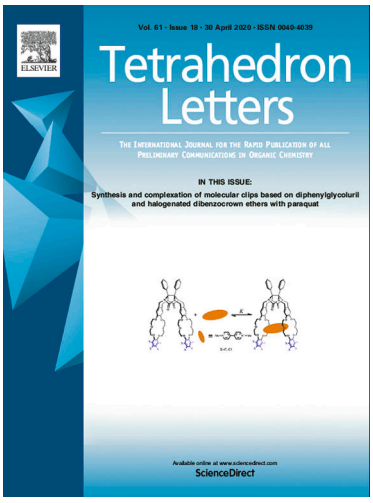
Journal Pre-proofs



Discovery of orthogonal synthesis using artificial intelligence: $Pd(OAc)_2$-catalyzed one-pot synthesis of benzofuran and bicyclo[3.3.1]nonane scaffolds

Tetsuhiko Takabatake, Keisuke Fujiwara, Sho Okamoto, Ryo Kishimoto, Natsuko Kagawa, Masahiro Toyota

PII: S0040-4039(20)30742-5
DOI: https://doi.org/10.1016/j.tetlet.2020.152275
Reference: TETL 152275

To appear in: *Tetrahedron Letters*

Received Date: 16 June 2020
Revised Date: 14 July 2020
Accepted Date: 19 July 2020

Please cite this article as: Takabatake, T., Fujiwara, K., Okamoto, S., Kishimoto, R., Kagawa, N., Toyota, M., Discovery of orthogonal synthesis using artificial intelligence: $Pd(OAc)_2$-catalyzed one-pot synthesis of benzofuran and bicyclo[3.3.1]nonane scaffolds, *Tetrahedron Letters* (2020), doi: https://doi.org/10.1016/j.tetlet.2020.152275

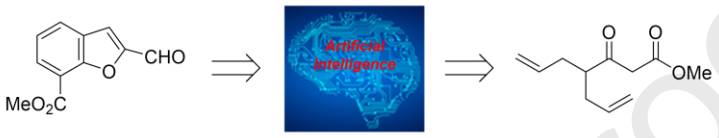
Graphical Abstract

To create your abstract, type over the instructions in the template box below.
Fonts or abstract dimensions should not be changed or altered.

Discovery of orthogonal synthesis using artificial intelligence: Pd(OAc)$_2$-catalyzed one-pot synthesis of benzofuran and bicyclo[3.3.1]nonane scaffolds

Leave this area blank for abstract info.

Tetsuhiko Takabatake, Keisuke Fujiwara, Sho Okamoto, Ryo Kishimoto, Natsuko Kagawa, and Masahiro Toyota



Tetrahedron Letters
journal homepage: www.elsevier.com

Discovery of orthogonal synthesis using artificial intelligence: $Pd(OAc)_2$-catalyzed one-pot synthesis of benzofuran and bicyclo[3.3.1]nonane scaffolds

Tetsuhiko Takabatake,[a] Keisuke Fujiwara,[b] Sho Okamoto,[b] Ryo Kishimoto,[b] Natsuko Kagawa,[c] and Masahiro Toyota[b,*]

[a] Advanced Materials Development Laboratory, Sumitomo Chemical Co., Ltd., 1-98, Kasugadenaka, 3-chome, Konohana-ku, Osaka, 554-8558
[b]Department of Chemistry, Graduate School of Science, Osaka Prefecture University, Sakai, Osaka 599-8531, Japan
[c]*Center for Environment, Health and Field Sciences, Chiba University, 6-2-1 Kashiwa-no-ha, Kashiwa, Chiba 277-0882, Japan.*

ARTICLE INFO

Article history:
Received
Received in revised form
Accepted
Available online

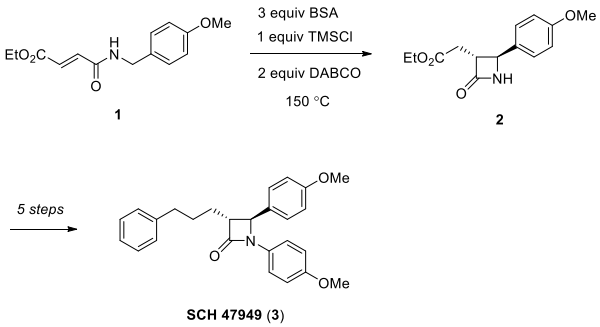
Keywords:
Artificial intelligence
$Pd(OAc)_2$ catalyst
benzofuran
bicyclo[3.3.1]nonane

ABSTRACT

A synthetic route for the common intermediate, methyl 2-formylbenzofuran-7-carboxylate (**7a**), to efficiently assemble three bioactive benzofurans **4**-**6** was explored using the artificial intelligence system SYNSUP. Among the routes proposed by SYNSUP, we investigated a three-step synthesis of **7a** using methyl 4-ally-3-oxohept-6-enoate (**10**). A new catalytic reaction was found in which **7a** was directly obtained from **10** in a single step with a yield of 24%. It was found that this chemical yield could be increased to 74% when methyl 3-allyl-2-hydroxybenzoate (**9a**), an intermediate of the above one-pot transformation, was subjected to the catalytic process. In addition, in this catalytic process, **8a** (76%) and **11** (77%) were each selectively synthesized from **10** by changing only the solvent. Therefore, we created a novel orthogonal synthesis of methyl 2-methylbenzofuran-7-carboxylate (**8a**) and methyl 9-oxobicyclo[3.3.1]nona-3,6-diene-1-carboxylate (**11**). Finally, the total syntheses of bioactive benzofurans **4**-**6** were completed smoothly using **7a** and **8a**.

Introduction

Artificial intelligence (AI) is defined as the ability of machines to interpret data, make decisions, and carry out tasks in a way similar to humans.[1] AI is already widely used in many commercial and scientific fields. Algorithms predict what we like, anticipate our behavior, and diagnose medical conditions with impressive speed. AI is also being used to identify diseases, and can even outperform human experts when it comes to diagnosing disease.[2] We are entering a world where conversation with machines is going to be both enlightening and more efficient in many areas. How is AI going to change our world? There are no certain answers to that question at the present time. In contrast, the first introduction of AI into the field of synthetic organic chemistry was more than 50 years ago, however, the evolution of AI in this field has been extremely slow.[3] One of the reasons is that it takes a significant amount of time to experimentally evaluate proposed synthetic routes using AI. Our laboratory has been engaged in the evolution of SYNSUP (an AI program)[4] since 2007. Recently, we have succeeded in the stereoselective synthesis of SCH 47949 (**3**), which inhibits the absorption of cholesterol from the small intestine, using SYNSUP (Scheme 1).[5] After tuning a part of the reaction substrate structure proposed by SYNSUP, basic treatment of **1** in the presence of two silylation reagents provided *trans* β-lactam **2** in a stereoselective manner. Finally, the five-step transformation of **2** proceeded smoothly and the desired SCH 47949 (**3**) was obtained in a reasonable chemical yield (Scheme 1). It is worth noting that the present functional group manipulation for the synthesis of **3** was identical to the synthetic routes proposed by SYNSUP.



Scheme 1. AI (SYNSUP)-designed total synthesis of SCH 47949 (**3**).

As part of our drug synthesis program using SYNSUP, we embarked on the creation of a potential intermediate to concisely synthesize bioactive benzofuran analogs. Not surprisingly, some rather simple benzofuran derivatives showed a wide variety of significant bioactivities. Among them, we especially became interested in unnatural bioactive products **4**-**6** (Figure 1).[6]

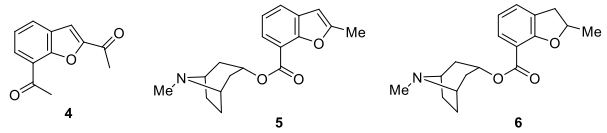
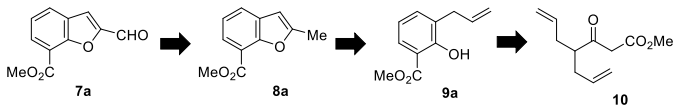


Figure 1. Structures of known bioactive benzofuran analogs **4**-**6**.

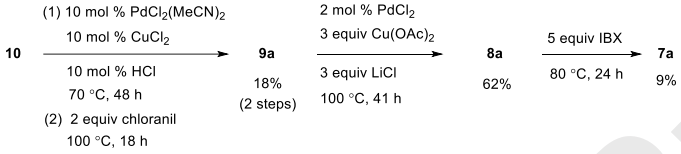
Unknown compound **7a** was selected as a potential intermediate for t… routes were searched using SYNSUP. As a result, 36 synthetic routes were proposed in a short time (see Supporting Information-1). We attempted to determine a method of synthesis of **7a** from methyl 4-allyl-3-oxohept-6-enoate (**10**), since this proposed route, shown below, involved a catalytic reaction reported by our laboratory (Scheme 2).[7]



Scheme 2. Retrosynthetic route for **7a** proposed by SYNSUP.

Results and Discussion

First, we investigated the transformation of **10** into **9a** using Orellana's protocol.[8] A $PdCl_2(MeCN)_2$-catalyzed cyclization of **10** followed by oxidation with two equivalent chloranil provided **9a** in an 18% yield, which was subjected to $PdCl_2$-catalyzed cyclization[9] to afford **8a** (62%). Finally, an allylic oxidation of **8a** was performed with IBX[10] to give the desired intermediate **7a** in a 9% yield. Accordingly, the total yield of the preparation of **7a** from **10** was only 1%. The extremely low chemical yield of the IBX oxidation at the allylic position in **8a** was the biggest problem with this process, and the transformation of **10** to **9a** was the first stumbling block. Incidentally, an allylic oxidation of **8a** using SeO_2 was completely unsuccessful (Scheme 3).



Scheme 3. Linear synthesis of **7a** from **10**.

Next, we applied $Pd(OAc)_2$-catalyzed cycloaromatization[7] to methyl 4-allyl-3-oxohept-6-enoate (**10**). Perhaps because the reactivity of substrate **10** to Pd (II) was extremely high, subtle differences in the reaction solvent, additive, reaction temperature, reaction time, and work-up method greatly affected the isolation yields of each product and the reproducibility of this process. Therefore, we tested the reaction conditions using 10 mol % $Pd(OAc)_2$ with a purity of 99.98% for the following investigations. Among various studies on the reaction conditions, some characteristic results are summarized in Table 1. When this reaction was carried out without either $Cu(OAc)_2$ or oxygen …ned. When substance **10** was treated with 10 mol % $Pd(OAc)_2$ in dimethyl sulfoxide (DMSO) in the presence of 20 mol % $Cu(OAc)_2$ at room temperature under one atmosphere of oxygen for 21 hours, methyl 9-oxobicyclo[3.3.1]nona-3,6-diene-1-carboxylate (**11**)[11] was obtained in a 43% yield, together with a 14% yield of methyl 3-allyl-2-hydroxybenzoate (**9a**) and an 8% yield of methyl 3-allyl-2-hydroxycyclohexa-1,4-diene-1-carboxylate (**13**) (Table 1, entry 1). This result suggested that both **9a** and **11** were produced from the common intermediate **13**. Samples were continuously taken from the reaction and monitored by TLC analysis. As a result, the first catalytic cyclization consumed approximately 7 hours and only the intermediate **13** was obtained in a 62% yield (Table 1, entry 2). To obtain methyl 2-methylbenzofuran-7-carboxylate (**8a**) as a major product, the amount of $Cu(OAc)_2$ was increased to 3 equivalents.[12, 13] Unfortunately, only 2-hydroxybenzoate **9a** was isolated in a 78% yield (Table 1, entry 3). At this point, we expected that heating must be required for the cyclization of phenol **9a**. On heating **9a** with 10 mol % $Pd(OAc)_2$ and 3 equivalents of $Cu(OAc)_2$ at 60 °C, it was found that the target molecule, methyl 2-formylbenzofuran-7-carboxylate (**7a**), was directly produced, although at a low yield (24%), along with a 13% yield of methyl 2-methylbenzofuran-7-carboxylate (**8a**) and a 21% yield of bicyclic compound **11** (Table 1, entry 4). The structure of **7a** was determined by NMR techniques (COSY, HMBC, HMQC). To efficiently obtain **7a**, the catalytic amount of $Pd(OAc)_2$ was increased to 20 mol %. Interestingly, not only were the chemical yields of **7a**, **8a**, and **11** decreased, but methyl 2*H*-chromene-8-carboxylate (**12**) was also produced *via* a *6-endo-trig* cyclization mode in a 10% yield (Table 1, entry 5).[14] When the reaction solvent was changed to MeCN, only benzofuran **8a** was obtained, in a 44% yield (Table 1, entry 6). The reaction was conducted using 10 mol % $Pd(OAc)_2$ and 1 equivalent $Cu(OAc)_2$ in MeCN at 50 ˚C in the presence of 2 equivalent DMSO[13] to furnish benzofuran **8a** in a 76% yield (Table 1, entry 7). To our surprise, changing MeCN to THF gave rise to bicyclo[3.3.1]nonane **11** in a 77% yield as a single isomer (Table 1, entry 7). It is worth mentioning that only Snider's group has reported the one-step preparation of **11** from **10** using radical reaction conditions; however, the chemical yield was 11% as a 2:1 mixture of the olefin isomers.[11] Because bicyclic compound **11** is highly functionalized, **11** could be used as a synthon for the

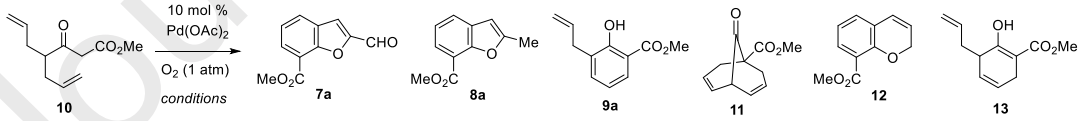


Table 1. Cyclization of methyl 4-allyl-3-oxohept-6-enoate (**10**).

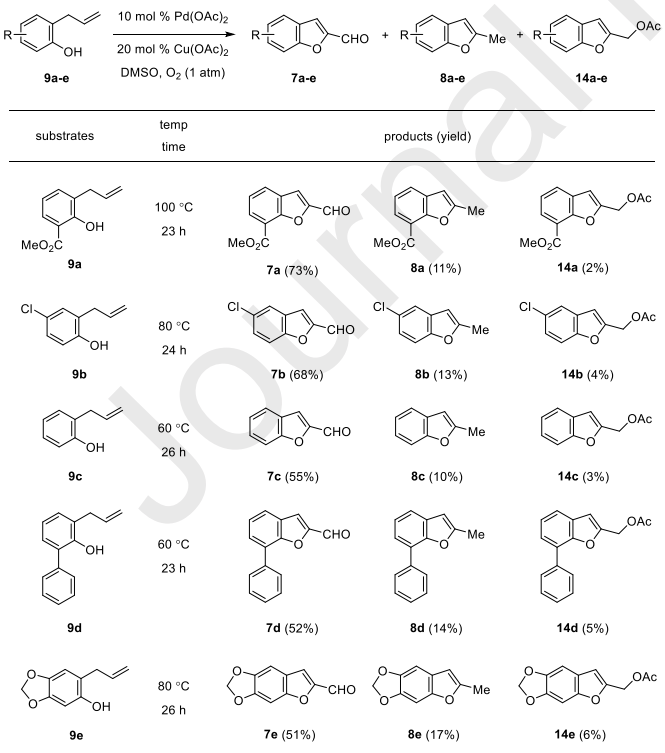
entry	$Cu(OAc)_2$ (mol %)	solevent	Additive (equiv)	temp (˚C)	time (h)	yield (%)					
						7a	**8a**	**9a**	**11**	**12**	**13**
1	20	DMSO	none	Rt	21	0	0	14	43	0	8
2	20	DMSO	none	Rt	7	0	0	0	0	0	62
3	300	DMSO	none	Rt	37	0	0	78	0	0	0
4	300	DMSO	none	60	23	24	13	0	21	0	0
5[a]	300	DMSO	none	60	24	10	10	0	5	10	0
6	300	MeCN	none	60	22	0	44	0	0	0	0
7	100	MeCN	DMSO (2)	50	26	0	76	0	0	0	0
8	20	THF	DMSO (2)	50	20	0	0	11	77	0	0
9	20	THF	none	50	24	0	0	16	19	0	0
10[b]	None	DMSO	none	60	24	0	0	0	0	0	53
11[c]	none	DMSO	none	60	24	0	0	0	0	0	65

(a) 20 mol % $Pd(OAc)_2$ was used. (b) 10 mol % $Pd(TFA)_2$ was used. (c) 10 mol % $PdCl_2$ was used.

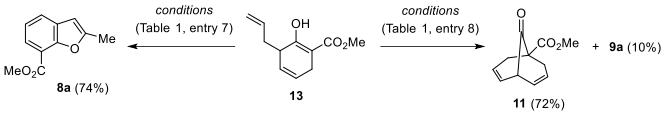
synthesis of terpenes, such as upial[15] and trifarienols.[16] It is obvi… to Pd(II) (Table 1, entry 9). Both $Pd(TFA)_2$ and $PdCl_2$ provided methyl 3-allyl-2-hydroxycyclohexa-1,4-diene-1-carboxylate (**13**), respectively, in a moderate yield (Table 1, entries 10 and 11). The cyclization reaction using other solvents such as DMF, CH_2Cl_2, and 1,4-dioxane was also investigated, but the chemical yield of each product was drastically reduced.

Since the direct conversion of **10** into **7a** was difficult, a detour route *via* the easily obtainable **9a** was examined. Scheme 4 summarizes the results of a $Pd(OAc)_2$-catalyzed one-pot synthesis of 2-formylbenzofuran **7a** using 2-allylphenol **9a** and the substrate scope. The electron-withdrawing group next to the hydroxyl group in **9a** resulted in an improvement in yield. For example, when **9a** was heated with 10 mol % $Pd(OAc)_2$ and 20 mol % $Cu(OAc)_2$ at 100 ˚C in DMSO under one atmosphere of oxygen for 23 hours, **7a** was isolated in a 73% yield, together with **8a** (11%) and acetate **14a** (2%). Substrate **9b** with an electron-withdrawing chloride at the para position of the benzene ring afforded the desired aldehyde **7b**, in a 68% yield, as well as **8b** (13%) and **14b** (3%). Unsubstituted 2-allylphenol **9c** furnished **7c** in a moderate yield, and also produced **8c** (10%) and **14c** (3%). On the other hand, substrate **9d** with an electron-donating group at the ortho position of the benzene ring produced **7d** in a 52% yield with **8d** (14%) and **14d** (5%). The methylenedioxy group in **9e** survived under the reaction conditions to give rise to **7e** (51%), **8e** (17%), and **14e** (6%). In this reaction, the electron-donating group tends to reduce the yield. All of the above products were easily isolated by flash column chromatography. It is worth emphasizing that there are no reports of a one-step conversion of 2-allylphenols **9** to 2-formylphenols **7**.

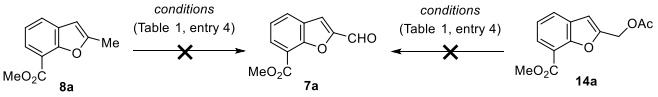
Scheme 4. $Pd(OAc)_2$-catalyzed one-pot synthesis of 2-formylbenzofurans **9a-e**.



Additional experiments were conducted as shown below to estimate the reaction mechanism of the cyclization reaction of compound **10**. By changing the reaction conditions, compounds **8a** and **11** can clearly be produced separately from the reaction intermediate **13** (Scheme 5). Additionally, the reaction conditions shown in entry 4 of Table 1 were applied to compound **8a** and compound **14a**, but neither compound produced 2-

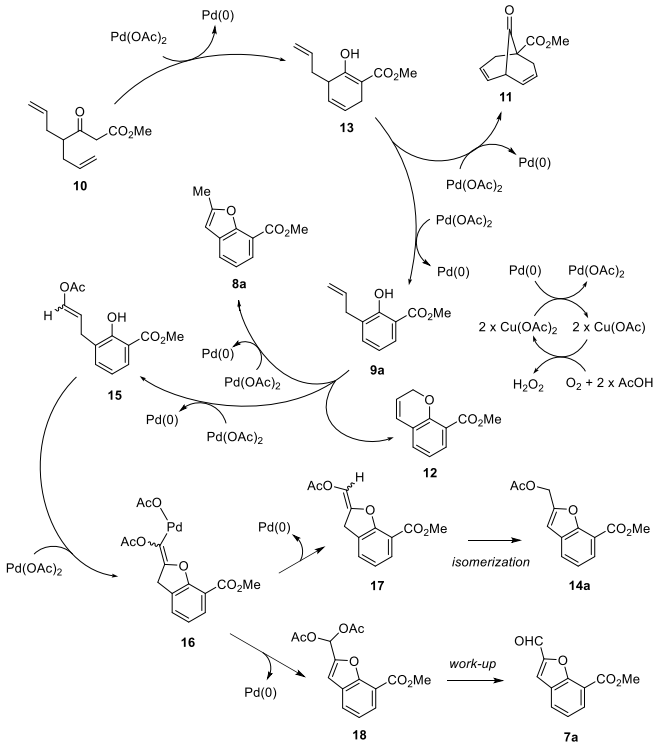


Scheme 5. Orthogonal cyclizations of 1,4-cyclohexadiene **13**.



Scheme 6. Transformational examination of **8a** and **14a**.

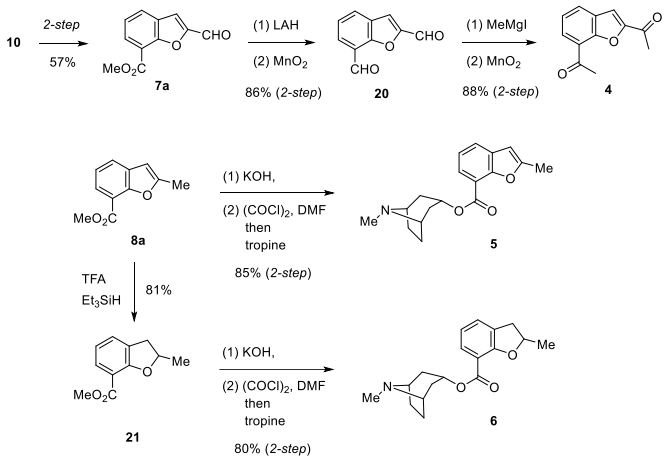
According to the experimental results, we proposed the reaction mechanism shown in Scheme 7. 2-Allylphenol **9a** and bicyclic compound **11** were produced *via* the monocyclization intermediate **13**.[17] By properly selecting the reaction temperature and the reaction solvent, **9a** and **11** can be produced separately. When the catalytic reaction of **10** was conducted in MeCN at 50 ˚C in the presence of 2 equivalents of DMSO, **8a** was obtained *via* **9a** as the sole product. The initial target molecule **7a** was directly obtained from acyclic compound **10**, although at a low yield of 24%. Based on the experimental results of Schemes 4-6, we considered how **7a** was generated. After a regioselective acetoxypalladation on the olefinic moiety in **9a**, intramolecular oxypalladation of **15** proceeded to lead to **16** as a mixture of stereoisomers.[18] Reductive elimination of **16** gave diacetate **18**, which was hydrolyzed to **7a**.[19] On the other hand, generation of the palladium-hydride species **17** followed by reductive elimination gave **18**, which isomerized to thermodynamically stable **14a**.[19, 18b.] The Pd(0) species produced in this process were reoxidized to $Pd(OAc)_2$ by $Cu(OAc)_2$ in the presence of oxygen. Additionally, since there might be oxidizing agents generated in the system, we cannot rule out that Pd(IV) is involved in the reaction mechanism.



Scheme 7. Plausible reaction mechanism.

With the desired compounds **7a** and **8a** in hand, we attempted to complete the total syntheses of bioactive benzofurans **4**-**6**. Ester

aldehyde **7a**, obtained from **10** by a two-step process in 57% over[illegible] Journal Pre-proofs [illegible]/.-D. oxidation to afford dialdehyde **20** (86% for two steps). Subsequent dimethylation and MnO_2 oxidation gave rise to diacetate **4** in an 88% yield through two steps. 2-Methylbenzofuran **8a** was transformed into the corresponding tropine ester **5** in an 85% overall yield utilizing hydrolysis followed by a Schottem–Baumann reaction. On the other hand, another tropine ester, **6,** was synthesized *via* **21**. Acidic reduction of the furan component in **8a** was conducted at 0 ˚C using TFA and Et_3SiH to furnish **21** in an 81% yield. Hydrolysis of **21** and a Schottem–Baumann reaction provided tropine ester **6** as a mixture of two diastereoisomers in an 80% overall yield. The spectroscopic properties of synthetic benzofurans **4-6** were identical with those reported for **4-6**, respectively (Scheme 8).[6]



Scheme 8. Total syntheses of bioactive benzofurans **4-6**.

Acknowledgements

We would like to thank Sumitomo Chemical for allowing us to use SYNSUP. We would also like to thank Professor Barry M. Trost (Stanford University) for the fruitful discussions regarding the reaction mechanism.

References and Notes

1. Russell S. J.; Norvig R. *Artificial Intelligence: A Modern Apporach*, Third Ed. Peason England, **2016**.
2. Chen Y, Argentinis, E, Weber G, *Clin. Ther*. 38 (2016) 688-701.
3. *A pioneering paper*: E. J. Corey, T. Wipke, *Science* 166 (1969) 178-192. *Some selected reviews*: see (a) M. Bersohn, A. Esack, *Chem. Rev*. 76 (1976) 269-282; (b) I. Ugi, J. Bauer, K. Bley, A. Dengler, A. Deitz, E. Fontain, B. Gruber, R. Herges, M. R. Knauer, N. Stein, *Angew. Chem. Int. Ed*. 32 (1993) 201-227; (c) W.-D. Ihlenfeldt, J. Gasteiger, *Angew. Chem. Int. Ed*. 34 (1995) 2613-2633; (d) M. H. Todd, *Chem. Soc. Rev*. 34 (2005) 247-266; (e) S. Szymkuć, E. P. Gajewska, T. Klucznik, K. Molga, P. Dittwald, M. Startek, M. Bajczyk, B. A. Grzybowski, *Angew. Chem. Int. Ed*. 55 (2016) 5904-5937; *Selected programs*: see (f) OCSS: E. J. Corey, T. Wipke, *Science* 166 (1969) 178-192; (g) LHASA: E. J. Corey, W. T. Wipke, R. D. Cramer III, W. J. Howe, *J. Am. Chem. Soc*. 94 (1972) 421-430; (h) SECS: W. T. Wipke, T. M. Dyott, *J. Am. Chem. Soc*. 96 (1974) 4825-4834; (i) CAMEO: T. D. Salatin, W. T. Jorgensen, *J. Org. Chem*. 45 (1980) 2043-2051; (j) SYNSUP: M. Bersohn, *Bull Chem. Soc. Jpn*. 45 (1972) 1897-1903; (k) SYNCHEM: H. L. Gelernter, A. F. Sanders, D. L. Larsen, K. K. Agarwal, R. H. Boivie, G. A. Spritzer, J. E. Searleman, *Science* 197 (1977) 1041-1049; (l) ARChem Route Designer: J. Law, Z. Zsoldos, A. Simon, D. Reid, Y. Liu, S. Y. Khew, A. P. Johnson, S. Major, R. A. Wade, H. Y. Ando, *J. Chem. Inf. Model*. 49 (2009) 593-602; (m) AIPHOS: K. Funatsu, S. Sasaki, Tetrahedron Comput. Methodol. 1 (1988) 27-37; (n) KOSP: K. Satoh, K. Funatsu, *J. Chem. Inf. Comput. Sci*. 39 (1999) 316-325; (o) SYNGEN: J. B. Hendrickson, *Angew. Chem. Int. Ed*. 29 (1990) 1286-1295; (p) CICLOPS: J. Blair, J. Gasteiger, C. Gillespie, P. D. Gillespie, I. Ugi, *Tetrahedron* 30 (1974) 1845-1859; (q) EROS: J. Gasteiger, C. Jochum, [illegible] Ihlenfeldt, P. Roese, *Red. Trav. Chim. Pays-Bas*. 111 (1992) 270-290; (s) CHIRON: S. Hanessian, J. France, G. Gagnon, D. Laramée, B. J. Larouche, *Chem. Inf. Comput. Sci*. 30 (1990) 413-425; (t) Chematica: S. Szymkuć, E. P. Gajewska, T. Klucznik, K. Molga, P. Dittwald, M. Startek, M. Bajczyk, B. A. Grzybowski, *Angew. Chem. Int. Ed.* 55 (2016) 5904-5937.
4. *Original program*: M. Bersohn, *Bull Chem. Soc. Jpn*. 45 (1972) 1897-1903; (b) *Selected papers related to the application*: T. Takabatake, M. Bersohn, *Pure Appl. Chem*. 62 (1990) 1977-1978.; A. Tanaka, T. Kawai, T. Takabatake, N. Oka, H. Okamoto, M. Bersohn, *Tetrahedron* 63 (2007) 10226-10236.
5. T. Takabatake, T. Yoneda, J. Otsuka, N. Kagawa, M. Toyota, *Tetrahedron Lett*. 60 (2019) 150942.
6. **Compound 1**: M. W. Khan, M. J. Alam, M. A. Rashid, R. Chowdhury, *Bioorg. Med. Chem*. 13 (2005) 4796-4805; **Compounds 2** and **3**: D. W. Robertson, W. B. Lacefield, W. Bloomquist, W. Pfeifer, R. L.Simon, M. L.Chen, *J. Med. Chem.* 35 (1992) 310-319.
7. M. Miyagi, S. Okada, N. Tada, M. Sugihara, N. Kagawa, T. Takabatake, M. Toyota, *Tetrahedron Lett*. 60 (2019) 1653-1657.
8. S. Samadi, A. Orellana, *ChemCatChem* 6 (2016) 2472-2475.
9. A.I. Roshchin, S.M. Kel'chevski, N.A. Bumagin, *J. Orgmet. Chem*. 560 (1998) 163-167.
10. K.C. Nicolaou, T. Montagnon, P.S. Baran, Y.-L. Zhong, *J. Am. Chem. Soc*. 124 (2002) 2245-2258.
11. M. R. Dombroski, B. B. Snider, *Tetrahedron*, 48 (1992) 1417-1426.
12. A. I. Roshchin, S. M. Kel'chevski, N. A. Bumagin, *J. Organomet. Chem*. 560 (1998) 163-167.
13. Y. Wu, Z. Huang, Y. Luo, D. Liu, Y. Deng, H. Yi, J.-F. Lee, C.-W. Pao, J.-L. Chen, A. Lei, *Org. Lett.* 19 (2017) 2330-2333.
14. R. C. Larock, L. Wei, T. R. Hightower, *Synlett*, (1998) 522-524.
15. G. Schulte, P. J. Scheuer, O. J. McConnell, *J. Org. Chem*. 45 (1980) 552-554.
16. T. Hashimoto, H. Koyama, S. Takaoka, M. Tori, Y. Asakawa, *Tetrahedron Lett*. 35 (1994) 4787-4788.
17. (a) M. Toyota, T. Wada, M. Ihara, *J. Am. Chem. Soc*. 120 (1998) 4916-4925. (b) M. Toyota, A. Ilangogovan, R. Okamoto, T. Masaki, M. Arakawa, M. Ihara, *Org. Lett*. 4 (2002) 4293-4296. (c) A. Hibi, M. Toyota, *Tetrahedron Lett*. 50 (2009) 4888-4891.
18. (a) P. Kočovský, and J.-E. Bäckvall, Chem. Eur. J. 21 (2015) 36-56. (b) J. Tsuji, *Palladium Reagents and Catalysts: Innovations in Organic Synthesis*, John Wiley & Sons, New York, 1995.
19. (a) M. L. O'Duill and K. M. Engle, *Synthesis* 50 (2018) 4699-4714. (2) R. I. McDonald, G. Liu, S. S. Stahl, *Chem. Rev*. 111 (2011) 2981-3019.

Graphical Abstract

To c
template box below.
Fonts or abstract dimensions should not be changed or altered.

Discovery of orthogonal synthesis using artificial intelligence: Pd(OAc)$_2$-catalyzed one-pot synthesis of benzofuran and bicyclo[3.3.1]nonane scaffolds

Leave this area blank for abstract info.

Tetsuhiko Takabatake, Keisuke Fujiwara, Sho Okamoto, Ryo Kishimoto, Natsuko Kagawa, and Masahiro Toyota