JOC The Journal of Organic Chemistry

Featured Article

Palladium-Catalyzed Intermolecular Azidocarbonylation of Alkenes via a Cooperative Strategy

Ming Li, Feng Yu, Pinhong Chen, and Guosheng Liu

J. Org. Chem., **Just Accepted Manuscript** • DOI: 10.1021/acs.joc.7b01812 • Publication Date (Web): 24 Aug 2017

ACS Publications

The Journal of Organic Chemistry is published by the American Chemical Society.
1155 Sixteenth Street N.W., Washington, DC 20036

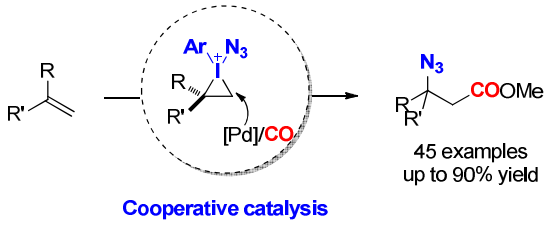
Palladium-Catalyzed Intermolecular Azidocarbonylation of Alkenes via a Cooperative Strategy

Ming Li,[†,§] Feng Yu,[†,§] Pinhong Chen*[†] and Guosheng Liu*[,†,‡]

[†]State Key Laboratory of Organometallic Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, University of Chinese Academy of Sciences, 345 Lingling Road, Shanghai 200032, China

[‡]Key Laboratory of Functional Molecular Engineering of Guangdong Province, South China University of Technology, Guangzhou 510640, China

Email: pinhongchen@sioc.ac.cn; gliu@mail.sioc.ac.cn

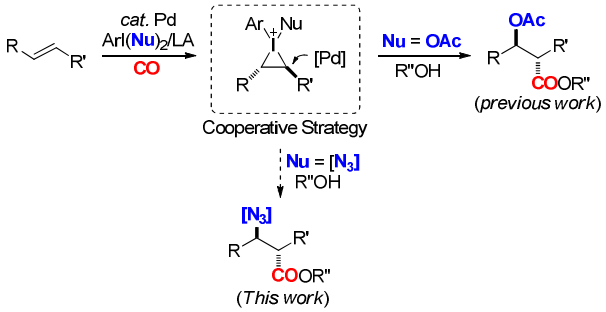


ABSTRACT: A novel intermolecular *β*-azidocarbonylation reaction of alkenes has been developed, in which a combination of iodine(III)-mediated alkene activation and palladium-catalyzed carbonylation was demonstrated as an efficient strategy for the difunctionalization of alkenes. A variety of *β*-azido carboxylic esters were obtained from mono- and 1,1-disubstituted terminal alkenes with excellent regioselectivities. In addition, the introduced azido group can be reduced to amine group, providing a facile access to *β*-amino acid derivatives from simple olefins.

INTRODUCTION

The carbonylation reaction is one of the most important alkene transformation reactions in homogeneous catalysis, especially in the chemical industry, and a large variety of valuable bulk and fine chemicals are produced by this method.[1] Despite the tremendous progress in this field, the reaction types are quite limited to hydrocarbonylation, possibly owing to the high reactivity of metal hydride complexes involved in these reactions.[2] Particularly, carbonylation-based difunctionalization reactions of alkenes (DFAs) are synthetically attractive.[3] However, the pioneering studies were limited to the type of intramolecular reactions,[4] and the intermolecular

counterparts of these DFAs are quite limited.[5] Thus, the exploration of new methods to promote intermolecular DFAs is of high synthetic significance.



Scheme 1. Cooperative Strategy for Intermolecular Alkene Difunctionalization

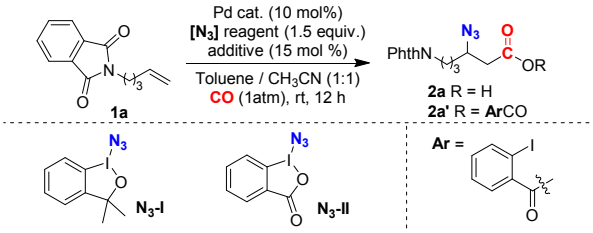
β-Amino acids have been identified as essential components in bioactive natural products and broadly utilized for the development of peptide-based pharmaceutical compounds, due to its biological metabolism property.[6] Thus, exploration of the efficient synthesis of *β*-amino acids and related derivatives has received much attention.[7] Recently, we reported a palladium-catalyzed intermolecular aminocarbonylation reaction of terminal alkenes and it serves as one of the most efficient approaches to the synthesis of *β*-amino acids.[8] However, the reaction was limited to the monosubstituted terminal alkenes. In order to address the reactivity of disubstituted alkenes, we have developed a novel cooperative strategy of iodine (III)-mediated C=C activation and palladium catalysis for the oxidative oxycarbonylation of alkenes, and various *β*-oxycarboxylic acids/esters have been synthesized under mild reaction conditions (Scheme 1).[9] Notably, this reaction showed much wider substrate scope, and both terminal and internal alkenes are suitable for this reaction. We surmised that if an amine-based iodine (III) could be applied to replace $PhI(OAc)_2$, an intermolecular *β*-aminocarbonylation of alkenes might be expected (Scheme 1). Considering the utility of azide, we assumed that an azido-based hypervalent iodine reagent should be a good choice.[10] Herein, we reported a novel palladium-catalyzed intermolecular azidocarbonylation of alkenes with Zhdankin I(III) reagents (**N_3-II**) as the azido source and $BF_3{\cdot}OEt_2$ as the activator.

RESULTS AND DISCUSSION

The initial study was focused on the reaction of terminal alkene **1a**, and two azido-based iodine(III) reagents[11] were employed to test the above hypothesis. As shown in Table 1, when the azido-based I(III) reagent **N_3-I** was tested in the palladium-catalyzed azidocarbonylation reaction

in the presence of $BF_3 \cdot OEt_2$, the reaction failed to give the desired product (entry 1). When the more reactive Zhdankin reagent **N_3-II** was tested, the reaction afforded the desired *β*-azidocarbonylation products **2a** (carboxylic acid) and **2a'** (anhydride) in 78% total yield (entry 2). Solvent screening revealed that acetonitrile is important for the reaction. The reaction in toluene alone could not afford the target product, however, the yield was slightly dropped in single acetonitrile (entries 3-4). Based on our previous oxycarbonylation reaction, $BF_3 \cdot OEt_2$ as a Lewis acid is required to activate **N_3-II**, which facilitates alkene activation to form a three-membered iodonium ion intermediate. Other Lewis and Brønsted acids were also screened, however, only strong Lewis and Brønsted acids, such as $Mg(ClO_4)_2$, HOTf and H_2SO_4 gave the desired product in decreased yields (entries 5-9). Moreover, the screening of palladium catalysts indicated that the use of $Pd(acac)_2$ instead of $Pd(OAc)_2$ could further improve the yield to 87% with high efficiency within 1 hour. The desired product was also formed under the catalysis of $Pd(OTFA)_2$ and $PdCl_2$ but with slightly lower yields. The use of cationic palladium catalyst only provided 15% yield, which indicated that the nucleophilicity of the palladium species is important for this reaction. No product was obtained under the catalysis of $Pd(PPh_3)_4$ (entries 10-14). Control experiments showed that no reaction took place in the absence of neither palladium catalyst nor $BF_3 \cdot OEt_2$. Only alkene isomerization has been observed when the reaction was carried out under the atmosphere of N_2 instead of CO (entries 15-17). For the sake of convenient purification, the crude product **2a** and **2a'** in entry 10 was treated with MeOH followed by $TMSCHN_2$ to give the corresponding methyl ester **3a** in 85% yield. It is worth noting that regioselectivities in all cases are above 20:1, which is corresponding to addition of the azido and carbonyl groups to the internal and terminal carbon atoms respectively.

Table 1. Optimization of Reaction Conditions.[a]

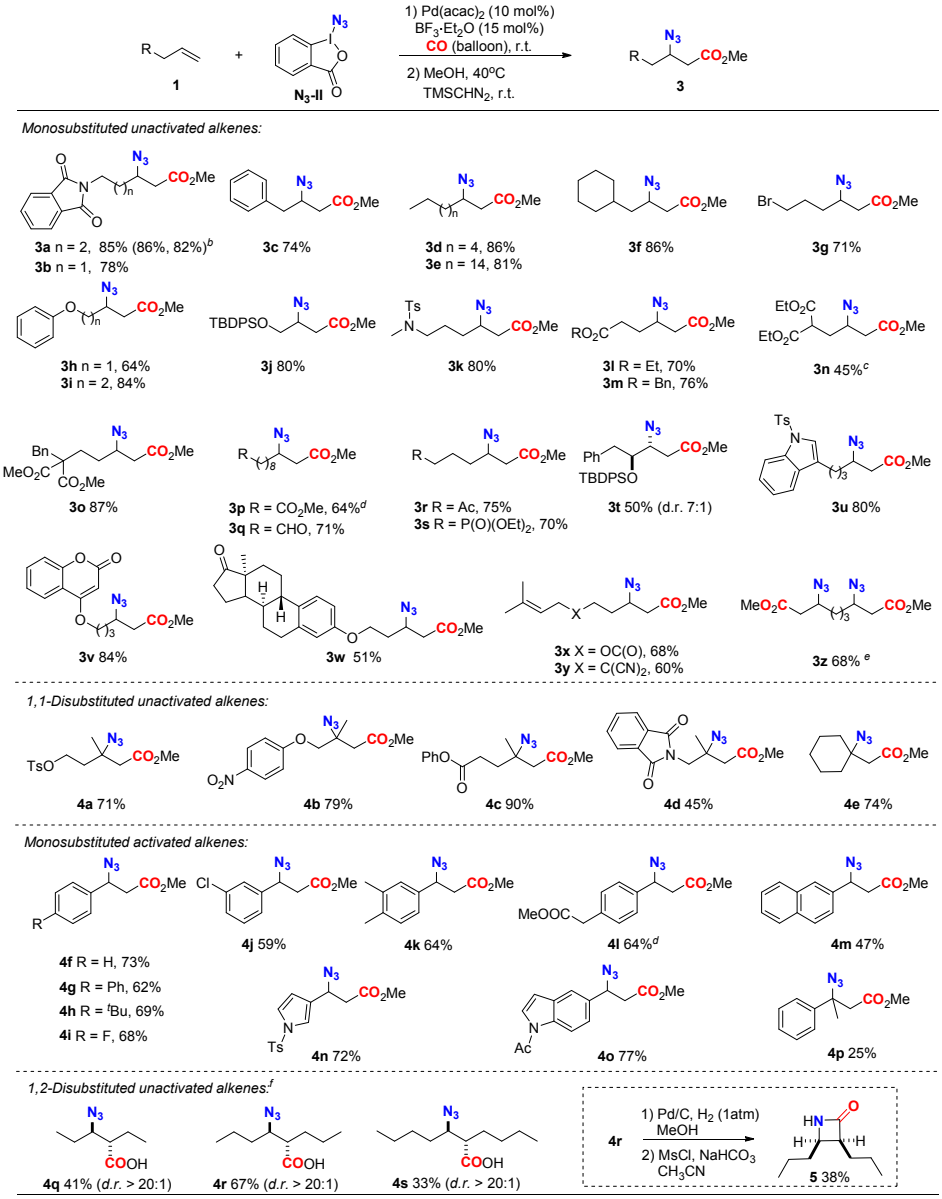


Entry	Pd cat.	[N_3] reagent	additive	**2a +2a'** Yield (%)[b]
1	$Pd(OAc)_2$	**N_3-I**	$BF_3•Et_2O$	0
2	$Pd(OAc)_2$	**N_3-II**	$BF_3•Et_2O$	78
3[c]	$Pd(OAc)_2$	**N_3-II**	$BF_3•Et_2O$	76
4[d]	$Pd(OAc)_2$	**N_3-II**	$BF_3•Et_2O$	0
5	$Pd(OAc)_2$	**N_3-II**	$Zn(OTf)_2$	0
6	$Pd(OAc)_2$	**N_3-II**	$Mg(ClO_4)_2$	22
7	$Pd(OAc)_2$	**N_3-II**	HOAc	0
8	$Pd(OAc)_2$	**N_3-II**	HOTf	63
9	$Pd(OAc)_2$	**N_3-II**	H_2SO_4	75
10	$Pd(acac)_2$	**N_3-II**	$BF_3•Et_2O$	87 (85[e], 85[f])
11	$Pd(OTFA)_2$	**N_3-II**	$BF_3•Et_2O$	52
12	$PdCl_2$	**N_3-II**	$BF_3•Et_2O$	62
13	$Pd(CH_3CN)_4(BF_4)_2$	**N_3-II**	$BF_3•Et_2O$	15
14	$Pd(PPh_3)_4$	**N_3-II**	$BF_3•Et_2O$	0
15	--	**N_3-II**	$BF_3•Et_2O$	0
16	$Pd(OAc)_2$	**N_3-II**	--	0
17[g]	$Pd(OAc)_2$	**N_3-II**	$BF_3•Et_2O$	0

[a]Reaction conditions: all reactions were run at 0.2 mmol scale. [b]^{1}H NMR Yield with CF_3-DMA as an internal standard, and regioselectivities in all cases are above 20:1. [c]CH_3CN was used as the solvent alone. [d]Toluene was used as the solvent alone. [e]Yield of ester **3a**. [f]1 h. [g]The reaction was carried out under the atmosphere of N_2 instead of CO.

With the optimized reaction conditions in hand, our attention turned to an exploration of the substrate scope of alkenes. The results (Table 2) show that aliphatic terminal alkenes undergo this reaction efficiently to yield the corresponding esters **3a–3s** in moderate to good yields. A number of functional groups, including imides, halides, ethers, esters, amides, ketones, aldehydes, phosphates are survived under the reaction conditions. Free acid group is compatible with this reaction, which is further methylated to give diester product **3p** in 64% yield. Noteworthy, excellent levels of regioselectivities are observed in all these reactions (>20:1). Also, the reaction of the *t*-butyldiphenylsilyl-protected allylic alcohol forms **3t** in 50% yield with 7:1 diastereoselectivity for the *anti* isomer. Furthermore, substrates containing heteroarenes are reactive to deliver the products **3u** and **3v** in 80% and 84% yields respectively. The reaction of substrate bearing estrone motif also affords the desired product **3w** in 51% yield. Interestingly, when dienes are used as the substrates, the reactions occur exclusively at the terminal alkene

Table 2. Substrate Scope of Alkenes.[a]

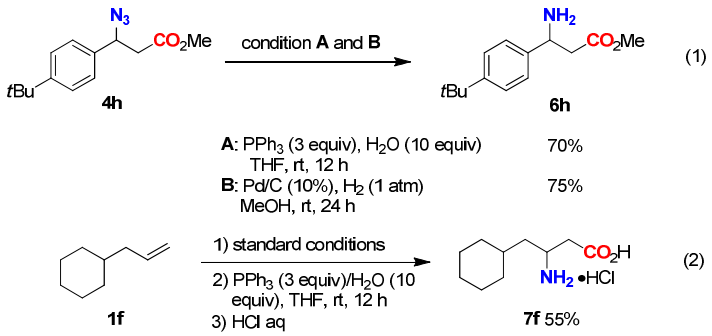


[a]All reaction conditions: substrate (0.2 mmol, 0.10 M), N_3-II (0.3 mmol), $Pd(acac)_2$ (0.02 mmol) and $BF_3{\cdot}Et_2O$ (0.03 mmol) in CH_3CN/Toluene (1:1) with CO balloon at room temperature, then esterified with MeOH only, or further with $TMSCHN_2$ (0~1.0 mmol). [b]Yields in 1 mmol and 5 mmol scales respectively. [c]50% substrate was remained. [d]Acid is used as the substrate. [e]N_3-II (0.6 mmol). [f]*E*-alkenes (0.2 mmol, 0.025 M), N_3-II (0.5 mmol), $Pd(hfacac)_2$ (0.02 mmol) and $BF_3{\cdot}Et_2O$ (0.04 mmol) in CH_3CN/Toluene (9:1) with CO balloon at room temperature.

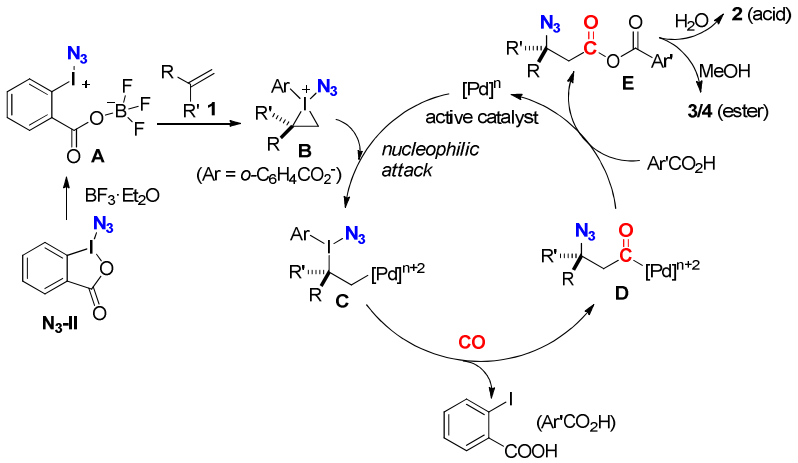
center to afford **3x** and **3y** in good yields, probably due to the steric effect. Therefore, the reaction

of 1,6-heptadiene affords the bis-azidocarbonylation product **3z** with a increased loading of azido reagent. It is worth noting that 1,1-disubstituted alkenes also work well in this reaction, affording **4a**-**4c** in good to excellent yields. The reaction of sterically hindered substrate affords the expected product **4d** as a single product in 45% yield. Exocyclic alkene also serves as a good substrate for this azidocarbonylation reaction to deliver product **4e** in 74% yield. Finally, the reactivity of styrene derivatives bearing different functional groups on the aryl rings was also surveyed. These reactions generate the desired products **4f-4l** in good yields. While the reaction of 2-vinylnaphthalene shows slightly lower reactivity, affording **4m** in only 47% yield. In comparison, vinylheteroarenes substrates are good for the reaction to deliver products **4n** and **4o** in good yields. Unfortunately, 1,1-disubstituted styrenes exhibited lower efficiency than the aliphatic 1,1-disubstituted alkenes (**4a**-**4e**), and the reaction provided the desired product **4p** in 25% yield. Based on the result of previous oxycarbonylation reaction, we turned our attention to survey the reactivity of internal alkenes. We were delighted to find that the reaction of (*E*)-oct-4-ene affords the desired product *anti*-**4r** in 67% yield. The reactions of (*E*)-hex-3-ene and (*E*)-dec-5-ene also proceed well to afford *anti*-**4q** and *anti*-**4s** in slightly low yields. Even though, these transformations are important, because these products are difficult to synthesize from other methods. To our delight, excellent diastereoselectivities were observed in this reaction (*d.r.* > 20:1). The stereochemistry, *anti* addition across the alkenes, is the same as that in oxycarbonylation reaction,[9] which is proved by transferring *anti*-**4r** to butyrolactam **5** through hydrogenation and substitution reactions.[12] Importantly, this reaction can be scaled up to 1 mmol and 5 mmol to provide product **3a** in excellent yields (86% and 82% respectively).

Due to the facile transformation of azido unit to amine group, we believed this reaction would be an efficient way for the generation of *β*-aminocarboxylic acid products. As shown in eq 1, the reaction of **4h** with either triphenylphosphine/H_2O or Pd/C under hydrogen atmosphere generated the amine product **6h** in good yields (70% and 75% repectively). To further prove the convenience of this reaction, *β*-amino acid **7f** can be accessible through sequential reactions from alkenes, including azidocarbonylation, reduction, and neutralization with hydrochloride through a easy-separated process (eq 2).



Based on the mechanism studies of our previous oxycarbonylation reaction,9 we proposed the similar mechanism for this azidocarbonylation (Scheme 2): First, Zhdankin reagent (**N_3-II**) is activated by $BF_3{\cdot}OEt_2$ to generate a more electron deficient iodine species **A**, which reacts with the alkene to form the three-membered iodonium ion intermediate **B**.[13] The nucleophilic attack of an activate palladium catalyst, which is not clear at this stage, affords the alkyl-Pd species **C**. Then, CO insertion into alkyl-Pd complex **C** and nucleophilic attack of azide at hypervalent iodine center generate the acyl-Pd species **D**, which is attacked by 2-iodobenzoic acid to give the anhydride product **E**. During the workup by water or MeOH, the related carboxylic ester **3** and **4** or carboxylic acid **2** were obtained.



Scheme 2. Proposed Mechanism for Azidocarbonylation Reaction

CONCLUSION

In summary, we have developed a novel transition-metal-catalyzed and iodine(III)-mediated, DFAs for *β*-azidocarboxylation. Both mono- and 1,1-disubstituted terminal alkenes participate. Some internal alkenes are also feasible to give the *anti*-azidocarboxylation products in excellent diastereoselectivity in slightly lower reactivity. The reaction, which is conducted under very mild reaction conditions, has good functional-group compatibility, broad substrate scope, and high

levels of regioselectivity. Due to the easy transformation of azido group, the current methodology presents a facile synthesis of *β*-amino acid derivatives from simple olefins. Further mechanistic studies and synthetic application are ongoing in our laboratory.

EXPERIMENTAL SECTION

General. $Pd(OAc)_2$ $Pd(acac)_2$ and $Pd(hfacac)_2$ was purchased from Strem Chemical, other commercial reagents with high purity were purchased and used without further purification, unless otherwise noted. Reactions were monitored by thin-layer chromatography (TLC) carried out on 25 mm silica gel plates. ^1H, ^{19}F and ^{13}C NMR spectra were recorded on an agilent-400 MHz spectrometer. The chemical shifts (δ) are given in parts per million relative to internal standard TMS (0 ppm for ^1H), $CDCl_3$ (77.0 ppm for ^{13}C). Highresolution mass spectra were carried out on mass spectrometer with Agilent Technologies 6224 TOF LC/MS for positive ions (ESI), Thermo Fisher Scientific LTQ FTICR-MS for negative ions (ESI), and Waters Micromass GCT Premier for EI. Flash column chromatography was performed on silica gel (particle size 200-300 mesh, purchased from Canada) and eluted with petroleum ether/ethyl acetate. Acetonitrile and toluene were directly obtained from solvent purification system of Innovation Technology Company.

General procedure A for Azidocarbonylation Reaction.

To a suspention of $Pd(acac)_2$ (6.0 mg, 0.02 mmol, 10 mol%), **N_3-II** reagent (86.7 mg, 0.3 mmol, 1.5 equiv) and alkene (0.2 mmol, 1.0 equiv) in toluene/CH_3CN (1:1, 2 mL) in a dried 25 mL Schlenk bottle under CO (1 atm) atmosphere, BF_3•Et_2O (0.03 mmol, 15 mol%) was added. The mixture was stirred at room temperature for 1-6 h. After the alkene was consumed, monitored by TLC, dried MeOH (2.0 mL) was added and the resulting mixture was stirred at 45 ^oC for 10 h. If the esterification process was not complete, the mixture was filtrated through a short silica gel and washed with ethyl acetate. The filtration was concentrated in vaccum and the residue was dissolved in MeOH/CH_3CN (1:1, 2 mL), added with $TMSCHN_2$ (1.0 mmol, 0.5 mL, 2.0 M). After stirring at room temperature for 2 h, the solvent was removed and the residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate to afford the products.

General procedure B for Azidocarbonylation Reaction.

To a suspention of $Pd(hfacac)_2$ (10.4 mg, 0.02 mmol, 10 mol%), **N_3-II** reagent (144.5 mg, 0.5 mmol, 2.5 equiv), and alkene (0.2 mmol, 1.0 equiv) in toluene/CH_3CN (1:9, 8 mL) in a dried 100 mL Schlenk bottle under CO (1 atm) atmosphere, BF_3•Et_2O (0.04 mmol, 20 mol%) was added. The mixture was stirred at room temperature for 12 h. After the alkene was consumed, monitored by TLC, the mixture was filtrated through a short silica gel and washed with ethyl acetate. After removed the solvent, the residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate to afford the products.

Methyl 3-azido-6-(1,3-dioxoisoindolin-2-yl)hexanoate (3a). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 53.7 mg (85%), white solid. mp 71.0 ~ 72.1°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.62 (m, 2H), 7.69 – 7.65 (m, 2H), 3.84 – 3.68 (m, 1H), 3.66 (t, *J* = 6.8 Hz, 2H), 3.65 (s, 3H), 2.45 (d, *J* = 6.8 Hz, 2H), 1.88 – 1.79 (m, 1H), 1.77 – 1.68 (m, 1H), 1.59 – 1.50 (m, 2H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.9, 168.3, 133.9, 131.9, 123.2, 58.7, 51.9, 39.3, 37.3, 31.7, 25.1; HRMS (ESI): m/z calcd for $C_{15}H_{20}N_5O_4^+$ $[M + NH_4]^+$ 334.1510, found 334.1517.

Methyl 3-azido-5-(1,3-dioxoisoindolin-2-yl)pentanoate (3b). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 47.2 mg (78%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 – 7.81 (m, 2H), 7.73 – 7.69 (m, 2H), 3.88 – 3.74 (m, 3H), 3.69 (s, 3H), 2.56 (d, *J* = 6.8 Hz, 2H), 1.95 – 1.86 (m, 1H), 1.84 – 1.75 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.8, 168.2, 134.1, 131.9, 123.3, 56.8, 52.0, 39.3, 34.7, 33.2; HRMS (ESI): m/z calcd for $C_{14}H_{18}N_5O_4^+$ $[M + NH_4]^+$ 320.1353, found 320.1359.

Methyl 3-azido-4-phenylbutanoate (3c). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 32.4 mg (74%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 -7.31 (m, 2H), 7.28 – 7.26 (m, 1H), 7.25 – 7.22 (m, 2H), 4.11 – 4.04 (m, 1H), 3.73 (s, 3H), 2.90 (dd, *J* = 13.6, 7.2 Hz, 1H), 2.84 (dd, *J* = 13.6, 6.4 Hz, 1H), 2.53 (dd, *J* = 16.4, 5.2 Hz, 1H), 2.47 (dd, *J* = 16.0, 8.0 Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 171.1, 136.7, 129.4, 128.7, 127.1, 60.2, 51.9, 40.6, 38.7; HRMS (ESI): m/z calcd for $C_{11}H_{13}N_3NaO_2^+$ $[M + Na]^+$ 242.0900, found 242.0906.

Methyl 3-azidononanoate (3d). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (40:1 to 20:1). 36.6 mg (86%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.82 – 3.75 (m, 1H), 3.72 (s, 3H), 2.48 (d, *J* = 7.2 Hz, 2H), 1.59 – 1.48 (m, 2H), 1.47 – 1.21 (m, 8H), 0.88 (t, *J* = 6.8 Hz, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.3, 59.2, 51.9, 39.4, 34.4, 31.6, 28.9, 25.9, 22.5, 14.0; HRMS (ESI): m/z calcd for $C_{10}H_{19}N_3NaO_2^+$ $[M + Na]^+$ 236.1369, found 236.1378.

Methyl 3-azidononadecanoate (3e). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (40:1 to 20:1). 57.1 mg (81%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.82 – 3.75 (m, 1H), 3.70 (s, 3H), 2.56 – 2.43 (d, *J* = 6.4 Hz, 2H), 1.58 – 1.48 (m, 2H), 1.47 – 1.05 (m, 28H), 0.87 (t, *J* = 6.4 Hz, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.2, 59.1, 51.9, 39.4, 34.3, 31.9, 29.68, 29.67, 29.65, 29.64, 29.63, 29.60, 29.50, 29.44, 29.35, 29.2, 25.9, 22.7, 14.1; HRMS (ESI): m/z calcd for $C_{20}H_{43}N_4O_2^+$ $[M + NH_4]^+$ 371.3381, found 371.3386.

Methyl 3-azido-4-cyclohexylbutanoate (3f). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 5:1). 38.9 mg (86%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.91 – 3.81 (m, 1H), 3.71 (s, 3H), 2.48 (d, *J* = 6.8 Hz, 2H), 1.83 – 1.64 (m, 4H), 1.51 – 1.39 (m, 2H), 1.36 – 1.07 (m, 5H), 1.03 – 0.81 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.2, 56.6, 51.9, 41.9, 39.8, 34.3, 33.6, 32.5, 26.4, 26.2, 26.0; HRMS (ESI): m/z calcd for $C_{11}H_{19}N_3NaO_2^+$ $[M + Na]^+$ 248.1369, found 248.1380.

Methyl 3-azido-6-bromohexanoate (3g). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 10:1). 35.5 mg (71%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.89 – 3.79 (m, 1H), 3.73 (s, 3H), 3.43 (t, *J* = 6.4 Hz, 2H), 2.56 (dd, *J* = 16.0, 7.6 Hz, 1H), 2.51 (dd, *J* = 16.0, 6.0 Hz, 1H), 2.12 – 1.88 (m, 2H), 1.81 – 1.56 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.9, 58.4, 52.1, 39.4, 32.9, 32.8, 29.0; HRMS (EI): m/z calcd for $C_7H_{12}BrNO_2$ $[M–N_2]^+$ 221.0051, found 221.0054.

Methyl 3-azido-4-phenoxybutanoate (3h). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography

on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 30.1 mg (64%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 – 7.28 (m, 2H), 7.01 – 6.97 (m, 1H), 6.93 – 6.90 (m, 2H), 4.26 – 4.20 (m, 1H), 4.10 (dd, *J* = 9.6, 4.8 Hz, 1H), 4.06 (dd, *J* = 9.6, 6.4 Hz, 1H), 3.75 (s, 3H), 2.72 (dd, *J* = 16.4, 5.2 Hz, 1H), 2.62 (dd, *J* = 16.4, 8.4 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.8, 158.0, 129.6, 121.5, 114.5, 69.6, 57.3, 52.1, 35.8; HRMS (EI): m/z calcd for $C_{11}H_{13}N_3O_3$ $[M]^+$ 235.0957, found 235.0955.

Methyl 3-azido-5-phenoxypentanoate (3i). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 41.8 mg (84%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 -7.28 (m, 2H), 6.98 – 6.94 (m, 1H), 6.92 – 6.90 (m, 2H), 4.21 – 4.14 (m, 1H), 4.13 – 4.05 (m, 2H), 3.73 (s, 3H), 2.64 (dd, *J* = 16.4, 5.2 Hz, 1H), 2.59 (dd, *J* = 14.4, 8.0 HZ, 1H), 2.10 – 2.02 (m, 1H), 1.98 – 1.90 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.0, 158.4, 129.5, 121.0, 114.5, 63.9, 56.3, 52.0, 39.5, 34.0; HRMS (ESI): m/z calcd for $C_{12}H_{19}N_4O_3^+$ $[M + NH_4]^+$ 267.1452, found 267.1458.

Methyl 3-azido-4-((tert-butyldiphenylsilyl)oxy)butanoate (3j). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 10:1). 63.7 mg (80%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, *J* = 6.9 Hz, 4H), 7.51 – 7.37 (m, 6H), 3.99 – 3.93 (m, 1H), 3.74 (dd, *J* = 10.8, 4.8 Hz, 1H), 3.71 (dd, *J* = 10.8, 5.2 Hz, 1H), 3.71 (s, 3H), 2.58 (dd, *J* = 16.0, 5.2 Hz, 1H), 2.47 (dd, *J* = 16.0, 8.8 Hz, 1H), 1.10 (s, 9H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.0, 135.6, 132.7, 130.0, 127.9, 66.1, 59.8, 52.0, 35.6, 26.7, 19.2; HRMS (ESI): m/z calcd for $C_{21}H_{31}N_4O_3Si^+$ $[M + NH_4]^+$ 415.2160, found 415.2169.

Methyl 3-azido-6-(N,4-dimethylphenylsulfonamido)hexanoate (3k). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 2:1). 56.9 mg (80%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.4 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 3.87 – 3.76 (m, 1H), 3.71 (s, 3H), 3.07-2.90 (m, 2H), 2.68 (s, 3H), 2.51 (d, *J* = 6.8 Hz, 2H), 2.41 (s, 3H), 1.73 – 1.48 (m, 4H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.3, 143.4, 134.2, 129.7, 127.3, 58.7, 52.0, 49.5, 39.4, 34.6, 31.3, 23.9, 21.59; HRMS (ESI): m/z calcd for $C_{15}H_{26}N_5O_4S^+$ $[M + NH_4]^+$ 372.1700, found 372.1706.

6-Ethyl 1-methyl 3-azidohexanedioate (3l). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 10:1). 32.1 mg (70%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.14 (q, *J* = 6.8 Hz, 2H), 3.93 – 3.80 (m, 1H), 3.72 (s, 3H), 2.52 (d, *J* = 6.8 Hz, 2H), 2.44 (m, 2H), 1.96 – 1.84 (m, 1H), 1.81 – 1.71 (m, 1H), 1.25 (t, *J* = 7.2 Hz, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.6, 170.8, 60.7, 58.4, 52.0, 39.3, 30.6, 29.6, 14.2; HRMS (ESI): m/z calcd for $C_9H_{16}N_3O_4^+$ $[M + H]^+$ 230.1135, found 230.1142.

6-Benzyl 1-methyl 3-azidohexanedioate (3m). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 44.2 mg (76%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 – 7.28 (m, 5H), 5.13 (s, 2H), 3.88 – 3.84 (m, 1H), 3.72 (s, 3H), 2.60 – 2.43 (m, 4H), 1.99 – 1.86 (m, 1H), 1.85 – 1.75 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.4, 170.8, 135.7, 128.6, 128.3, 128.3, 66.6, 58.3, 52.0, 39.3, 30.6, 29.5; HRMS (ESI): m/z calcd for $C_{14}H_{21}N_4O_4^+$ $[M + NH_4]^+$ 309.1557, found 309.1563.

1,1-Diethyl 4-methyl 3-azidobutane-1,1,4-tricarboxylate (3n). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 5:1). 27.1 mg (45%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.21 (dq, *J* = 14.4, 7.2 Hz, 4H), 3.93 – 3.84 (m, 1H), 3.72 (s, 3H), 3.57 (dd, *J* = 9.2, 5.2 Hz, 1H), 2.56 (d, *J* = 6.8 Hz, 2H), 2.19 – 2.12 (m, 1H), 2.00 – 1.93 (m, 1H), 1.27 (q, *J* = 7.6 Hz, 6H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.6, 168.8, 168.7, 61.84, 61.79, 57.1, 52.1, 48.9, 39.6, 33.5, 14.03, 13.98; HRMS (ESI): m/z calcd for $C_{12}H_{23}N_4O_6^+$ $[M + NH_4]^+$ 319.1612, found 319.1620.

Trimethyl 2-azido-6-phenylhexane-1,5,5-tricarboxylate (3o). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 65.6 mg (87%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 – 7.20 (m, 3H), 7.05 (d, *J* = 6.4 Hz, 2H), 3.80 – 3.73 (m, 1H), 3.72 (s, 3H), 3.71 (s, 3H), 3.70 (s, 3H), 3.23 (s, 2H), 2.51 (dd, *J* = 16.0, 7.2 Hz, 1H), 2.47 (dd, *J* = 18.4, 6.4 Hz, 1H), 2.02 – 1.90 (m, 1H), 1.88 – 1.75 (m, 1H), 1.63 – 1.41 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.3, 171.2, 170.9, 135.5, 129.7, 128.4, 127.2, 58.9,

58.5, 52.52, 52.50, 52.0, 39.1, 38.6, 29.2, 28.5; HRMS (ESI): m/z calcd for $C_{18}H_{27}N_4O_6^+$ [M + NH_4]$^+$ 395.1925, found 395.1930.

Dimethyl 3-azidododecanedioate (3p). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 10:1). 38.3 mg (64%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.80 – 3.73 (m, 1H), 3.70 (s, 3H), 3.64 (s, 3H), 2.47 (d, *J* = 6.4 Hz, 2H), 2.28 (t, *J* = 7.6 Hz, 2H), 1.64 – 1.55 (m, 2H), 1.56 – 1.22 (m, 12H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.3, 171.2, 59.1, 51.9, 51.4, 39.4, 34.3, 34.0, 29.18, 29.11, 29.06, 29.02, 25.9, 24.9; HRMS (ESI): m/z calcd for $C_{14}H_{29}N_4O_4^+$ [M + NH_4]$^+$ 317.2183, found 317.2188.

Methyl 3-azido-12-oxododecanoate (3q). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 10:1). 38.2 mg (71%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.75 (t, *J* = 1.6 Hz, 1H), 3.81 – 3.74 (m, 1H), 3.71 (s, 3H), 2.48 (d, *J* = 6.4 Hz, 2H), 2.41 (td, *J* = 7.2, 1.6 Hz, 2H), 1.65 – 1.58 (m, 2H), 1.56 – 1.47 (m, 2H), 1.47 – 1.22 (m, 10H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 202.9, 171.3, 59.1, 51.9, 43.9, 39.4, 34.3, 29.2, 29.1, 29.0, 25.9, 22.0; HRMS (ESI): m/z calcd for $C_{13}H_{27}N_4O_3^+$ [M + NH_4]$^+$ 287.2083, found 287.2083.

Methyl 3-azido-7-oxooctanoate (3r). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 4:1). 32.0 mg (75%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.76 (q, *J* = 7.2 Hz, 1H), 3.68 (s, 3H), 2.48 (d, *J* = 7.2 Hz, 2H), 2.45 (t, *J* = 7.2 Hz, 2H), 2.11 (s, 3H), 1.78 – 1.54 (m, 2H), 1.54 – 1.42 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 208.0, 171.0, 58.9, 51.9, 42.8, 39.2, 33.6, 29.9, 19.9; HRMS (ESI): m/z calcd for $C_9H_{19}N_4O_3^+$ [M + NH_4]$^+$ 231.1452, found 231.1454.

Methyl 3-azido-6-(diethoxyphosphoryl)hexanoate (3s). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with DCM/ MeOH (1:0 to 10:1). 43.0 mg (70%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.15 – 3.99 (m, 4H), 3.82 – 3.75 (m, 1H), 3.70 (s, 3H), 2.49 (d, *J* = 6.8 Hz, 2H), 1.83 – 1.50 (m, 6H), 1.30 (t, *J* = 7.2 Hz, 6H); ^{13}C{1H} NMR (100 MHz, $CDCl_3$) δ 171.0, 61.6 (d, *J* = 6.3 Hz), 58.6 (d, *J* = 1.6 Hz), 52.0, 39.2, 35.0 (d, *J* = 15.8 Hz), 25.2 (d, *J* = 141.2 Hz),

19.1 (d, J = 4.1 Hz), 16.4 (d, J = 6.0 Hz); HRMS (ESI): m/z calcd for $C_{11}H_{23}N_3O_5P^+$ $[M + H]^+$ 308.1370, found 308.1371.

Methyl 3-azido-4-((tert-butyldiphenylsilyl)oxy)-5-phenylpentanoate (3t). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 48.7 mg (50%; d.r. 7:1), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.72 (m, 2H), 7.63 – 7.56 (m, 2H), 7.53 – 7.35 (m, 6H), 7.21 – 7.11 (m, 3H), 6.83 – 6.76 (m, 2H), 4.05 (ddd, J = 8.0, 5.6, 2.0 Hz, 1H), 3.83 (ddd, J = 8.0, 5.6, 2.0 Hz, 1H), 3.67 (s, 3H), 2.78 (dd, J = 14.0, 5.6 Hz, 1H), 2.69 (dd, J = 14.0, 8.4 Hz, 1H), 2.47 – 2.37 (m, 2H), 1.09 (s, 9H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.4, 137.0, 136.1, 135.9, 133.5, 133.0, 130.0, 129.8, 129.2, 128.5, 127.9, 127.7, 126.6, 76.6, 62.0, 52.0, 39.9, 34.7, 26.9, 19.3; HRMS (ESI): m/z calcd for $C_{28}H_{37}N_4O_3Si^+$ $[M + NH_4]^+$ 505.2629, found 505.2637.

Methyl 3-azido-6-(1-tosyl-1H-indol-3-yl)hexanoate (3u). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 20:1). 70.4 mg (80%), white solid. mp 94.1 ~ 95.5°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, J = 8.0 Hz, 1H), 7.74 (d, J = 8.4 Hz, 2H), 7.46 (d, J = 7.6 Hz, 1H), 7.32 (s, 1H), 7.31 (t, J = 8.0 Hz, 1H), 7.22 (t, J = 7.6 Hz, 1H), 7.19 (d, J = 8.4 Hz, 2H), 3.83 (q, J = 6.8 Hz, 1H), 3.71 (s, 3H), 2.69 (t, J = 7.6 Hz, 2H), 2.56 – 2.43 (m, 2H), 2.32 (s, 3H), 1.93 – 1.70 (m, 2H), 1.64 – 1.53 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.1, 144. 8, 135.4, 135.2, 130.8, 129.8, 126.7, 124.7, 123.1, 122.8, 122.5, 119.4, 113.8, 58.9, 52.0, 39.4, 34.0, 25.2, 24.5, 21.5; HRMS (ESI): m/z calcd for $C_{22}H_{28}N_5O_4S^+$ $[M + NH_4]^+$ 458.1857, found 458.1861.

Methyl 3-azido-6-((2-oxo-2H-chromen-4-yl)oxy)hexanoate (3v). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 55.6 mg (84%), white solid. mp 57.3 ~ 58.8°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (dd, J = 7.6, 0.9 Hz, 1H), 7.53 (td, J = 7.6, 0.9 Hz, 1H), 7.28 (t, J = 8.8 Hz, 2H), 5.65 (s, 1H), 4.15 (t, J = 6.0 Hz, 2H), 3.97 – 3.85 (m, 1H), 3.71 (s, 3H), 2.61 (dd, J = 16.0, 8.0 Hz, 1H), 2.55 (dd, J = 16.0, 5.6 Hz, 1H), 2.17 – 1.93 (m, 2H), 1..85 – 1.67 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.9, 165.4, 162.9, 153.3, 132.5, 123.9, 122.9, 116.8, 115.5, 90.6, 68.6, 58.6, 52.1, 39.3, 30.9, 25.2; HRMS

(ESI): m/z calcd for $C_{16}H_{18}N_3O_5^+$ $[M + H]^+$ 332.1241, found 332.1241.

Methyl 3-azido-5-(((8*R*,9*S*,13*S*)-13-methyl-17-oxo-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[*a*]phenanthren-3-yl)oxy)pentanoate (3w). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 43.4 mg (51%), pale yellow solid. mp 61.5 ~ 62.3°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, *J* = 8.4 Hz, 1H), 6.72 (dd, *J* = 8.4, 2.8 Hz, 1H), 6.65 (d, *J* = 2.4 Hz, 1H), 4.19 – 4.12 (m, 1H), 4.11 – 4.01 (m, 2H), 3.73 (s, 3H), 2.92 – 2.88 (m, 2H), 2.65 (dd, *J* = 16.0, 4.8 Hz, 1H), 2.56 (dd, *J* = 16.0, 4.4 Hz, 1H), 2.50 (dd, *J* = 19.2, 8.8 Hz, 1H), 2.42 – 2.37 (m, 1H), 2.27 – 2.22 (m, 1H), 2.18 – 1.86 (m, 6H), 1.70 – 1.37 (m, 6H), 0.91 (s, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 221.0, 171.0, 156.5, 137.8, 132.4, 126.4, 114.5, 112.1, 63.9, 56.3, 52.0, 50.4, 48.0, 44.0, 39.5, 38.3, 35.9, 34.0, 31.6, 29.7, 26.5, 25.9, 21.6, 13.9; HRMS (ESI): m/z calcd for $C_{24}H_{35}N_4O_4^+$ $[M + NH_4]^+$ 443.2653, found 443.2661.

1-Methyl 6-(3-methylbut-2-en-1-yl) 3-azidohexanedioate (3x). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 5:1). 36.6 mg (68%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.33 (t, *J* = 6.8 Hz, 1H), 4.58 (d, *J* = 7.2 Hz, 2H), 3.94 – 3.80 (m, 1H), 3.71 (s, 3H), 2.52 (d, *J* = 6.8 Hz, 2H), 2.50 – 2.38 (m, 2H), 1.90 (m, 1H), 1.81 – 1.72 (m, 1H), 1.75 (s, 3H), 1.70 (s, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.6, 170.8, 139.4, 118.3, 61.6, 58.4, 52.0, 39.3, 30.6, 29.6, 25.8, 18.0; HRMS (ESI): m/z calcd for $C_{12}H_{23}N_4O_4^+$ $[M + NH_4]^+$ 287.1714, found 287.1719.

Methyl 3-azido-6,6-dicyano-9-methyldec-8-enoate (3y). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 4:1). 34.7 mg (60%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.31 – 5.21 (m, 1H), 3.96 – 3.90 (m, 1H), 3.74 (s, 3H), 2.69 (d, *J* = 8.0 Hz, 2H), 2.63 (dd, *J* = 16.4, 8.0 Hz, 1H), 2.57 (dd, *J* = 16.4, 5.2 Hz, 1H), 2.20 – 2.09 (m, 1H), 2.04 – 1.87 (m, 2H), 1.82 (s, 3H), 1.86 – 1.74 (m, 1H), 1.72 (s, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.5, 141.1, 115.3, 115.2, 114.2, 57.9, 52.2, 39.2, 37.5, 36.3, 33.6, 30.6, 26.0, 18.4; HRMS (ESI): m/z calcd for $C_{14}H_{23}N_6O_2^+$ $[M + NH_4]^+$ 307.1877, found 307.1879.

Dimethyl 3,7-diazidononanedioate (3z). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography

on silica gel with petroleum ether/ ethyl acetate (20:1 to 5:1). 40.5 mg (68%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.86 – 3.76 (m, 2H), 3.72 (s, 6H), 2.58 – 2.44 (m, 4H), 1.69 – 1.46 (m, 6H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 171.0, 58.8, 52.0, 39.3, 33.9, 22.4; HRMS (ESI): m/z calcd for $C_{11}H_{22}N_7O_4^+$ $[M + NH_4]^+$ 316.1728, found 316.1736.

Methyl 3-azido-3-methyl-5-(tosyloxy)pentanoate (4a). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 48.4 mg (71%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, J = 8.0 Hz, 2H), 7.35 (d, J = 8.0 Hz, 2H), 4.13 (t, J = 6.4 Hz, 2H), 3.66 (s, 3H), 2.50 (s, 2H), 2.44 (s, 3H), 2.07 – 1.88 (m, 2H), 1.40 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 169.9, 145.0, 132.6, 129.9, 127.9, 66.2, 60.4, 51.9, 43.6, 37.9, 23.7, 21.7; HRMS (ESI): m/z calcd for $C_{14}H_{23}N_4O_5S^+$ $[M + NH_4]^+$ 359.1384, found 359.1388.

Methyl 3-azido-3-methyl-4-(4-nitrophenoxy)butanoate (4b). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 5:1). 46.4 mg (79%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (d, J = 9.2 Hz, 2H), 6.99 (d, J = 9.2 Hz, 2H), 4.20 (d, J = 9.2 Hz, 1H), 4.12 (d, J = 9.2 Hz, 1H), 3.70 (s, 3H), 2.77 (d, J = 15.2 Hz, 1H), 2.69 (d, J = 15.2 Hz, 1H), 1.54 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 169.9, 163.0, 141.9, 125.9, 114.6, 73.5, 60.7, 52.0, 40.6, 21.0; HRMS (ESI): m/z calcd for $C_{12}H_{18}N_5O_5^+$ $[M + NH_4]^+$ 312.1302, found 312.1304.

1-Methyl 6-phenyl 3-azido-3-methylhexanedioate (4c). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (15:1 to 5:1). 52.4 mg (90%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, J = 7.6 Hz, 2H), 7.55 (t, J = 7.2 Hz, 1H), 7.43 (t, J = 7.6 Hz, 2H), 4.52 – 4.39 (m, 2H), 3.66 (s, 3H), 2.65 (d, J = 15.1 Hz, 1H), 2.61 (d, J = 15.1 Hz, 1H), 2.24 – 2.07 (m, 2H), 1.51 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.1, 166.4, 133.0, 130.0, 129.5, 128.4, 60.81, 60.79, 51.8, 43.7, 37.7, 23.8; HRMS (ESI): m/z calcd for $C_{14}H_{21}N_4O_4^+$ $[M + NH_4]^+$ 309.1557, found 309.1562.

Methyl 3-azido-4-(1,3-dioxoisoindolin-2-yl)-3-methylbutanoate (4d). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 5:1). 27.1 mg

(45%), yellow solid. mp 52.8 ~ 54.0°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 – 7.84 (m, 2H), 7.77 – 7.71 (m, 2H), 3.91 (d, *J* = 14.0 Hz, 1H), 3.86 (d, *J* = 14.0 Hz, 1H), 3.72 (s, 3H), 2.61 (d, *J* = 15.6 Hz, 1H), 2.56 (d, *J* = 15.6 Hz, 1H), 1.52 (s, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.9, 168.4, 134.3, 131.7, 123.6, 62.1, 51.9, 45.2, 42.0, 21.7; HRMS (ESI): m/z calcd for $C_{14}H_{18}N_5O_4^+$ $[M + NH_4]^+$ 320.1353, found 320.1360.

Methyl 2-(1-azidocyclohexyl)acetate (4e). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 20:1). 29.9 mg (74%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.71 (s, 3H), 2.54 (s, 2H), 1.80 – 1.76 (m, 2H), 1.62 – 1.50 (m, 7H), 1.31 – 1.21 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.4, 62.0, 51.8, 44.7, 34.7, 25.1, 21.9; HRMS (ESI): m/z calcd for $C_9H_{15}N_3O_2Na^+$ $[M + Na]^+$ 220.1056, found 220.1063.

Methyl 3-azido-3-phenylpropanoate (4f). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 30.0 mg (73%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 – 7.33 (m, 5H), 4.99 (dd, *J* = 9.2, 5.2 Hz, 1H), 3.71 (s, 3H), 2.83 (dd, *J* = 16.0, 9.6 Hz, 1H), 2.70 (dd, *J* = 16.0, 4.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.7, 138.3, 129.0, 128.7, 126. 8, 62.2, 52.1, 41.1; HRMS (EI): m/z calcd for $C_{10}H_{11}NO_2$ $[M–N_2]^+$ 177.0790, found 177.0789.

Methyl 3-([1,1'-biphenyl]-4-yl)-3-azidopropanoate (4g). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 34.6 mg (62%), white solid. mp 38.5 ~ 39.0°C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 – 7.56 (m, 4H), 7.47 – 7.35 (m, 5H), 5.05 (dd, *J* = 9.2, 5.2 Hz, 1H), 3.73 (s, 3H), 2.87 (dd, *J* = 16.0, 9.2 Hz, 1H), 2.75 (dd, *J* = 16.0, 5.2 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.6, 141.6, 140.3, 137.2, 128.8, 127.7, 127.6, 127.2, 127.1, 61.9, 52.1, 41.1; HRMS (ESI): m/z calcd for $C_{16}H_{19}N_4O_2^+$ $[M + NH_4]^+$ 299.1503, found 299.1502.

Methyl 3-azido-3-(4-(tert-butyl)phenyl)propanoate (4h). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 20:1). 36.0 mg (69%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, *J* = 8.4 Hz, 2H), 7.26 (d, *J* =8.4 Hz, 2H), 4.97 (dd, *J* = 9.6, 4.8 Hz, 1H), 3.72 (s, 3H), 2.82 (dd, *J* = 16.0, 9.6 Hz, 1H), 2.69 (dd, *J* = 16.0, 4.8 Hz,

1H), 1.32 (s, 9H); $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 170.8, 151.7, 135.3, 126.4, 125.9, 61.9, 52.0, 41.1, 34.6, 31.3; HRMS (ESI): m/z calcd for $C_{14}H_{19}N_3O_2Na^+$ $[M + Na]^+$ 284.1369, found 284.1373.

Methyl 3-azido-3-(4-fluorophenyl)propanoate (4i). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 30.3 mg (68%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (dd, *J* = 8.8, 5.2 Hz, 2H), 7.08 (t, *J* = 8.8 Hz, 2H), 4.98 (dd, *J* = 8.8, 5.6 Hz, 1H), 3.70 (s, 3H), 2.81 (dd, *J* = 16.0, 8.8 Hz, 1H), 2.67 (dd, *J* = 16.0, 5.6 Hz, 1H); $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 170.5, 162.7 (d, *J* = 245.9 Hz), 134.1(d, *J* = 3.1 Hz), 128.5 (d, *J* = 8.4 Hz), 115.9 (d, *J* = 21.2 Hz), 61.5, 52.1, 41.2; HRMS (EI): m/z calcd for $C_{10}H_{10}NO_2F$ $[M–N_2]^+$ 195.0696, found 195.0701.

Methyl 3-azido-3-(3-chlorophenyl)propanoate (4j). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 15:1). 28.2 mg (59%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 – 7.30 (m, 3H), 7.22 (s, 1H), 4.97 (dd, *J* = 9.2, 5.2 Hz, 1H), 3.71 (s, 3H), 2.79 (dd, *J* = 16.0, 9.2 Hz, 1H), 2.67 (dd, *J* = 16.0, 5.2 Hz, 1H); $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 140.5, 134.9, 130.3, 128.9, 126.9, 124.9, 61.6, 52.1, 41.1; HRMS (EI): m/z calcd for $C_{10}H_{10}NO_2Cl$ $[M–N_2]^+$ 211.0400, found 211.0402.

Methyl 3-azido-3-(3,4-dimethylphenyl)propanoate (4k). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 30.0 mg (64%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 – 7.02 (m, 3H), 4.92 (dd, *J* = 9.2, 4.8 Hz, 1H), 3.71 (s, 3H), 2.81 (dd, *J* = 16.0, 9.6 Hz, 1H), 2.68 (dd, *J* = 16.0, 5.2 Hz, 1H), 2.28 (s, 3H), 2.26 (s, 3H); $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 170.8, 137.3, 137.2, 135.6 130.1, 128.0, 124.1, 62.0, 52.0, 41.1, 19.9, 19.5; HRMS (ESI): m/z calcd for $C_{12}H_{19}N_4O_2^+$ $[M + NH_4]^+$ 251.1503, found 251.1508.

Methyl 3-azido-3-(4-(2-methoxy-2-oxoethyl)phenyl)propanoate (4l). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (20:1 to 3:1). 35.5 mg (64%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 – 7.27 (m, 4H), 4.97 (dd, *J* = 9.2, 5.2 Hz, 1H), 3.70 (s, 3H), 3.69 (s, 3H), 3.63 (s, 3H), 2.80 (dd, *J* = 16.0, 9.2 Hz, 1H), 2.67 (dd, *J* = 16.1, 5.2

Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 171.6, 170.5, 137.2, 134.5, 129.9, 126.9, 61.9, 52.0, 52.0, 41.1, 40.7; HRMS (ESI): m/z calcd for $C_{13}H_{19}N_4O_4^+$ $[M + NH_4]^+$ 295.1401, found 295.1403.

Methyl 3-azido-3-(naphthalen-2-yl)propanoate (4m). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (1:0 to 10:1). 24.0 mg (47%), colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.92 – 7.79 (m, 4H), 7.54 –7.44 (m, 3H), 5.18 (dd, *J* = 9.2, 5.6 Hz, 1H), 3.72 (s, 3H), 2.92 (dd, *J* = 16.0, 9.2 Hz, 1H), 2.79 (dd, *J* = 16.0, 5.2 Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.7, 135.6, 133.3, 133.1, 129.1, 128.1, 127.8, 126.6, 126.5, 126.2, 124.1, 62.4, 52.1, 41.2; HRMS (ESI): m/z calcd for $C_{14}H_{17}N_4O_2^+$ $[M + NH_4]^+$ 273.1346, found 273.1357.

Methyl 3-azido-3-(1-tosyl-1H-pyrrol-3-yl)propanoate (4n). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (15:1 to 4:1). 53.2 mg (76%), pale yellow solid. mp 74.1 ~ 75.6°C. ^1H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 7.18 – 7.12 (m, 2H), 6.26 (dd, *J* = 3.2, 1.6 Hz, 1H), 4.85 (dd, *J* = 8.8, 5.6 Hz, 1H), 3.68 (s, 3H), 2.74 (dd, *J* = 16.0, 8.8 Hz, 1H), 2.65 (dd, *J* = 16.0, 5.6 Hz, 1H), 2.40 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.4, 145.3, 135.6, 130.1, 126.9, 126.0, 121.9, 118.3, 111.9, 55.4, 52.0, 40.2, 21.6; HRMS (ESI): m/z calcd for $C_{15}H_{20}N_5O_4S^+$ $[M + NH_4]^+$ 366.1231, found 366.1239.

Methyl 3-(1-acetyl-1H-indol-5-yl)-3-azidopropanoate (4o). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH and further with $TMSCHN_2$, and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 44.0 mg (77%), yellow solid. mp 54.2 ~ 55.2°C. ^1H NMR (400 MHz, $CDCl_3$) δ 8.45 (d, *J* = 8.4 Hz, 1H), 7.54 (d, *J* = 1.2 Hz, 1H), 7.45 (d, *J* = 3.6 Hz, 1H), 7.31 (dd, *J* = 8.8, 1.6 Hz, 1H), 6.65 (d, *J* = 3.6 Hz, 1H), 5.09 (dd, *J* = 9.2, 5.2 Hz, 1H), 3.70 (s, 3H), 2.88 (dd, *J* = 16.0, 9.2 Hz, 1H), 2.74 (dd, *J* = 16.0, 5.2 Hz, 1H), 2.64 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.7, 168.6, 135.6, 133.7, 130.7, 126.1, 123.8, 119.3, 117.1, 109.1, 62.3, 52.0, 41.4, 23.9; HRMS (ESI): m/z calcd for $C_{14}H_{18}N_5O_3^+$ $[M + NH_4]^+$ 304.1404, found 304.1411.

Methyl 3-azido-3-phenylbutanoate (4p). It was prepared according to procedure A in 0.2 mmol scale, esterified with MeOH only and purified by column chromatography on silica gel with

petroleum ether/ ethyl acetate (1:0 to 10:1). 11.0 mg (25%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.27 (m, 5H), 3.61 (s, 3H), 2.83 (s, 2H), 1.86 (s, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 169.9, 142.5, 128.6, 127.9, 125.4, 64.4, 51.8, 46.4, 24.9; HRMS (ESI): m/z calcd for $C_{11}H_{17}N_4O_2^+$ $[M + NH_4]^+$ 237.1346, found 237.1339.

***Anti*- 3-azido-2-ethylpentanoic acid (4r)**. It was prepared according to procedure B in 0.2 mmol scale and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 14.0 mg (41%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.58 -3.48 (m, 1H), 2.55 – 2.45 (m, 1H), 1.80 – 1.53 (m, 4H), 1.05 (t, J = 6.8 Hz, 3H), 0.98 (t, J = 7.2 Hz, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 179.1, 65.0, 51.1, 24.7, 22.0, 11.5, 10.3; HRMS (ESI): m/z calcd for $C_7H_{12}N_3O_2^-$ $[M-H]^-$ 170.0935, found 170.0933.

***Anti*-3-azido-2-propylhexanoic acid (4r)**. It was prepared according to procedure B in 0.2 mmol scale and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 26.6 mg (67%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.58 -3.48 (m, 1H), 2.55 – 2.45 (m, 1H), 1.72 – 1.25 (m, 8H), 0.97 (t, J = 7.2 Hz, 3H), 0.94 (t, J = 6.8 Hz, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 191.6, 63.7, 37.1, 33.8, 30.9, 20.5, 19.2, 13.9, 13.7; HRMS (ESI): m/z calcd for $C_9H_{16}N_3O_2^-$ $[M-H]^-$ 198.1248, found 198.1248.

***Anti*-3-azido-2-butylheptanoic acid (4s)**. It was prepared according to procedure B in 0.2 mmol scale and purified by column chromatography on silica gel with petroleum ether/ ethyl acetate (10:1 to 3:1). 15.0 mg (33%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.55 – 3.50 (m, 1H), 2.54 – 2.48 (m, 1H), 1.72 – 1.25 (m, 12H), 0.93 (t, J = 6.8 Hz, 3H), 0.91 (t, J = 5.6 Hz, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 178.7, 63.8, 49.9, 31.4, 29.3, 28.5, 28.1, 22.5, 22.4, 13.9, 13.8; HRMS (ESI): m/z calcd for $C_{11}H_{20}N_3O_2^-$ $[M-H]^-$ 226.1561, found 226.1561.

***Cis*-3,4-dipropylazetidin-2-one (5)**. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.06 (m, 1H), 3.29 (dt, J = 6.8, 2.4 Hz, 1H), 2.74 (dt, J = 6.0, 2.7 Hz, 1H), 1.80 – 1.73 (m, 1H), 1.65 – 1.55 (m, 3H), 1.49 – 1.32 (m, 4H), 0.96 (t, J = 7.2 Hz, 3H), 0.94 (t, J = 5.6 Hz, 3H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 171.7, 56.7, 55.2, 37.3, 30.7, 20.6, 19.7, 14.0, 13.9. Known compound.[14]

Typical procedure for Reduction of Azides.

To a solution of **4h** (26.1 mg, 0.1 mmol) in THF (1 mL) was added PPh_3 (78.6 mg, 0.3 mmol) and H_2O (18 μL, 1.0 mmol). The reaction solution was stirred at rt overnight. TLC indicated the completion of the substrate. The solution was concentrated and the residue was purified by

column chromatography on silica gel with dichloromethane/ methanol (1:0 to 10:1) to afford **6h** as colorless oil. 16.5 mg (70%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (d, *J* = 8.8 Hz, 2H), 7.28 (d, *J* = 8.4 Hz, 2H), 4.41 (t, *J* = 6.8 Hz, 1H), 3.69 (s, 3H), 2.68 (d, *J* = 6.8 Hz, 2H), 2.28 (br, 2H), 1.31 (s, 9H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.5, 150.4, 125.8, 125.5, 52.1, 51.7, 43.6, 34.3, 31.3. Known compound.[15]

3-Amino-4-cyclohexylbutanoic acid hydrochloride (7f). It was prepared according to procedure A in 0.2 mmol scale, after the alkene was consumed monitored by TLC, the reaction mixture was concentrated and reduced with PPh_3 (157 mg, 0.6 mmol) and H_2O (36 μL, 2.0 mmol) in THF (2 mL) for 12 h. HCl aq (6N, 1 mL) was then added, and the aquous phase was washed with ethyl acetate and concentrated to give crude solid. The solid was recrystallised in mixture of EtOH:H_2O to afford **6f** as a white solid. 24.3 mg (55%). mp 158 ~ 160°C. ^{1}H NMR (400 MHz, D_2O) δ 3.73 – 3.64 (m, 1H), 2.78 (dd, *J* = 15.6, 4.4 Hz, 1H), 2.63 (dd, *J* = 15.6, 8.0 Hz, 1H), 1.71 – 1.51 (m, 7H), 1.37 – 1.34 (m, 1H), 1.25 – 1.09 (m, 3H), 0.96 – 0.87 (m, 2H). ^{13}C{^{1}H} NMR (100 MHz, D_2O) δ 174.7, 45.9, 39.5, 36.4, 32.8, 32.29, 32.26, 25.7, 25.42, 25.39. Known compound.[16]

ASSOCIATED CONTENT

Author Contributions

§ M. Li and F. Yu contributed equally to this work.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

We are grateful for financial support from the National Basic Research Program of China (973-2015CB856600), the National Nature Science Foundation of China (Nos. 21532009, 21472217, and 21421091), and the Strategic Priority Research Program of the Chinese Academy of Sciences (No. XDB20000000). This research was also partially supported by Open Fund of the Key Laboratory of Functional Molecular Engineering of Guangdong Province, South China University of Technology (2016kf02).

Supporting Information

^{1}H and ^{13}C NMR spectra of all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

REFERENCES

(1) (a) Hartwig, J. F. *Organotransition Metal Chemistry: From Bonding to Catalysis*, University Science Books: **2010**. (b) Kollär, L. *Modern Carbonylation Methods*, Wiley-VCH, **2008**. (c) Beller, M. Catalytic Carbonylation Reactions, Springer, **2006**. (d) Gehrtz, P. H.; Hirschbeck, V.; Ciszek, B.; Fleischer, I. *Synthesis* **2016**, *48*, 1573. (e) Bai, Y.; Davis, D. C.; Dai, M. *J. Org. Chem*. **2017**, *82*, 2319.

(2) For reviews, see: (a) Franke, R.; Selent, D.; Börner, A. *Chem. Rev*. **2012**, *112*, 5675. (b) Kiss, G. *Chem. Rev*. **2001**, *101*, 3435. (c) van Leeuwen, P. W. N. M.; Claver, C. *Rhodium Catalyzed Hydroformylation*, Springer, **2000**. For recent selected examples, see: (d) Dong, K.; Fang, X.; Gülak, S.; Franke, R.; Spannenberg, A.; Neumann, H.; Jackstell, R.; Beller, M. *Nat. Commun.* **2017**, *8*, 14117. (e) Nobbs, J. D.; Low, C. H.; Stubbs, L. P.; Wang, C.; Drent, E.; van Meurs, M. *Organometallics* **2017**, *36*, 391. (f) Li, H.; Dong, K.; Jiao, H.; Neumann, H.; Jackstell, R.; Beller, M. *Nat. Chem.* **2016**, *8*, 1159.

(3) For reviews on DFAs, see: (a) Surhone, L. M.; Tennoe, M. T.; Henssonow, S. F. *Vicinal Difunctionalization*, Betascript Publishing, Saarbrücken, **2010**. (b) McDonald, R. I.; Liu, G.; Stahl, S. S. *Chem. Rev.* **2011**, *111*, 2981. (c) Romero, R. M.; Woeste, T. H.; Muniz, K. *Chem. Asian J.* **2014**, *9*, 972. (d) Wolfe, J. P. *Top. Heterocycl. Chem*. **2013**, *32*, 1. (e) Shimizu, Y.; Kanai, M. *Tetrahedron Lett*. **2014**, *55*, 3727. (f) Chemler, S. R.; Bovino, M. T. *ACS Catal.* **2013**, *3*, 1076. (g) Jensen, K. H.; Sigman, M. S. *Org. Biomol. Chem.* 2008, 6, 4083.

(4) For some reviews including intramolecular aminocarbonylation of alkenes, see: (a) Chiusoli, G. P.; Costa, M. *Handbook of Organopalladium Chemistry for Organic Synthesis*, Negishi, E.-I. Ed., Wiley, New York, **2002**, P 2595. (b) Wu, X.-F.; Fang, X.; Wu, L.; Jackstell, R.; Neumann, H.; Beller, M. *Acc. Chem. Res.* **2014**, *47*, 1041. (c) Wu, X.-F.; Neumann, H.; Beller, M. *Chem. Rev.* **2013**, *113*, 1. (d) Tamaru, Y.; Kimura, M. *Synlett.* **1997**, 749.

(5) (a) James, D. E.; Stille, J. K. *J. Am. Chem. Soc.* **1976**, *98*, 1810. (b) Urata, H.; Fujita, A.; Fuchikami, T. *Tetrahedron Lett.* **1988**, *29*, 4435. (c) Phan, N. H. T.; Furuya, T. Takahiro, S.; Ukaji, Y. *Chem. Lett.* **2016**, *45*, 1431.

(6) (a) Lelais, G.; Seebach, D. *Biopolymers* **2004**, *76*, 206. (b). Seebach, D.; Beck, A. K.; Bierbaum, D. J. *Chem. Biodiversity* **2004**, *1*, 1111. (c) Seebach, D.; Matthews, J. L. *J. Chem. Soc., Chem. Commun*. **1997**, 2015.

(7) (a) Cheng, R. P.; Gellman, S. H.; DeGrado, W. F. *Chem. Rev*. **2001**, *101*, 3219. (b) Sibi, M. P.; Manyem, S. *Tetrahedron* **2000**, *56*, 8033.

(8) Cheng, J.; Qi, X.; Li, M.; Chen, P.; Liu, G. *J. Am. Chem. Soc*. **2015**, *137*, 2480.

(9) (a) Li, M.; Yu, F.; Qi, X.; Chen, P.; Liu, G. *Angew. Chem. Int. Ed.* **2016**, *55*, 13843. For a recent study on the fluorocarbonylation, see: (b) Qi, X.; Yu, F.; Chen, P.; Liu, G. *Angew. Chem. Int. Ed.* **2017**, *56*, DIO: 10.1002/anie.201706401.

(10) (a) Scriven, E. F. V.; Turnbull, K. *Chem. Rev*. **1988**, *88*, 297; (b) Huryn, D. M.; Okabe, M. *Chem. Rev.* **1992**, *92*, 1745; (c) Bräse, S.; Gil, C.; Knepper, K.; Zimmermann, V. *Angew. Chem. Int. Ed.* **2005**, *44*, 5188; (d) S. Bräse, K. Banert, *Organic Azides*: *Syntheses and Applications*, Wiley-VCH, Weinheim, **2010**; (e) Song, W.; Kozhushkov, S. I.; Ackermann, L. *Angew. Chem. Int. Ed.* **2013**, *52*, 6576; (f) Jung, N.; Bräse, S. *Angew. Chem. Int. Ed.* **2012**, *51*, 12169; (g) Hennessy, E. T.; Betley, T. A. *Science* **2013**, *340*, 591.

(11) (a) Zhdankin, V. V.; Stang, P. J. *Chem. Rev.* **2008**, *108*, 5299. (b) Zhdankin, V. V. *Current Org. Synth.* **2006**, *2*, 121. (c) *Hypervalent Iodine in Organic Chemistry: Chemical Transformation*, Moriatry, R. M.; Prakash, O. Eds, Wiley-Interscience, New York, **2008**. (d) Varvoglis, A. *Hypervalent Iodine in Organic Synthesis*, Academic Press, London, **1997**. (e) Zhdankin, V. V.; Krasutsky, A. P.; Kuehl, C. J.; Simonsen, A. J.; Woodward, J. K.; Mismash, B.; Bolz, J. T. *J. Am. Chem. Soc*. **1996**, *118*, 5192.

(12) Loewe, M.F., Cvetovich, R. J., Hazen, G. G. *Tetrahedron Let.* **1991**, *32*, 2299.

(13) Charpentier, J.; Früh, N.; Togni, A. *Chem. Rev.* **2015**, *115*, 650.

(14) Pinazzi, C. P.; Noireaux, P.; Reyx, D. *Macromol. Chem. Phys*. **1975**, *176*, 2905.

(15) Zhao, D.; Sun, B.; Ren, J.; Li, F.; Song, S.; Lv, X.; Hao, C.; Cheng, M. *Bioorg. Med. Chem.* **2015**, *23*, 1356.

(16) Prasad, J. V. N. V.; Loo, J. A.; Boyer, F. E.; Stier, M. A.; Gogliotti, R. D.; Turner, W. J.; Harvey, P. J.; Kramer, M. R.; Mack, D. P.; Scholten, J. D.; Gracheck, S. J.; Domagala, J. M. *Bioorg. Med. Chem.* **1998**, *6*, 1707.