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Ruthenium-Catalyzed Synthesis of 5-Amino-1,2,3-triazole-4-carboxylates for Triazole-Based Scaffolds: Beyond the Dimroth Rearrangement

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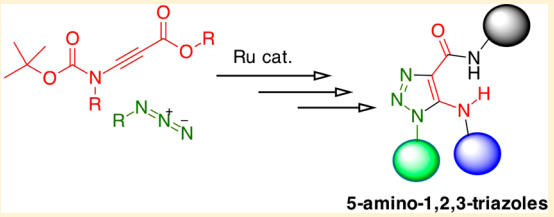
Supporting Information

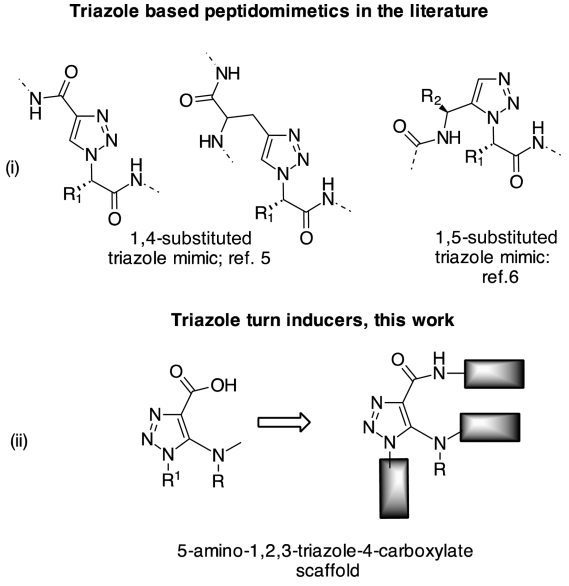
ABSTRACT: The 5-amino-1,2,3-triazole-4-carboxylic acid is a suitable molecule for the preparation of collections of peptidomimetics or biologically active compounds based on the triazole scaffold. However, its chemistry may be influenced by the possibility of undergoing the Dimroth rearrangement. To overcome this problem, a protocol based on the ruthenium-catalyzed cycloaddition of *N*-Boc ynamides with azides has been developed to give a protected version of this triazole amino acid. When aryl or alkyl azides are reacted with *N*-Boc-aminopropiolates or arylynamides, the cycloaddition occurs with complete regiocontrol, while *N*-Boc-alkyl ynamides yield a mixture of regioisomers. The prepared amino acids were employed for the preparation of triazole-containing dipeptides having the structural motives typical of turn inducers. In addition, triazoles active as HSP90 inhibitors (as compound **41**, IC_{50} = 29 nM) were synthesized.



INTRODUCTION

The development of compounds that mimic peptide secondary structure is one of the most useful approaches for the design and synthesis of new chemical entities interacting with biological targets.[1] Over the years, a big effort has been devoted to the synthesis of constrained peptidomimetics in order to better understand the bioactive conformations or to improve bioavailability or generic metabolic stability.[2] The incorporation into a peptide chain of (hetero)cyclic scaffolds able to restrict conformational freedom has been shown to be a valuable tool to enhance some molecular properties such as stability to proteases, potency, and receptor selectivity.[3] Of particular interest is the use of aromatic and heteroaromatic structures as dipeptide isosters that have found interesting applications in the preparation of active peptidomimetics.[2a] In the wake of the recent increase of interest for triazoles, several examples of triazole-based amino acids or peptide scaffolds have been described.[4] 1,2,3-Triazoles have been demonstrated to be effective turn inducers for conformationally constrained peptide analogues. In the first papers, the triazole scaffold was produced by Cu-catalyzed cycloaddition between α-azido acids (derived from α-amino acids) and N- or C-propargyl derivatives.[5] Afterward, the Ru-catalyzed synthesis of a 1,5-disubstituted 1,2,3-triazole as a proline mimic has been described.[6] However, most of the examples report 1,4- or 1,5-disubstituted triazoles carrying the carboxyl and the amino groups on the carbon chain relatively far from the triazole itself (Scheme 1 (i)).

Scheme 1



A potentially useful alternative is the 5-amino-(1*H*)-1,2,3-triazole-4-carboxylate scaffold (Scheme 1 (ii)), a triazole amino

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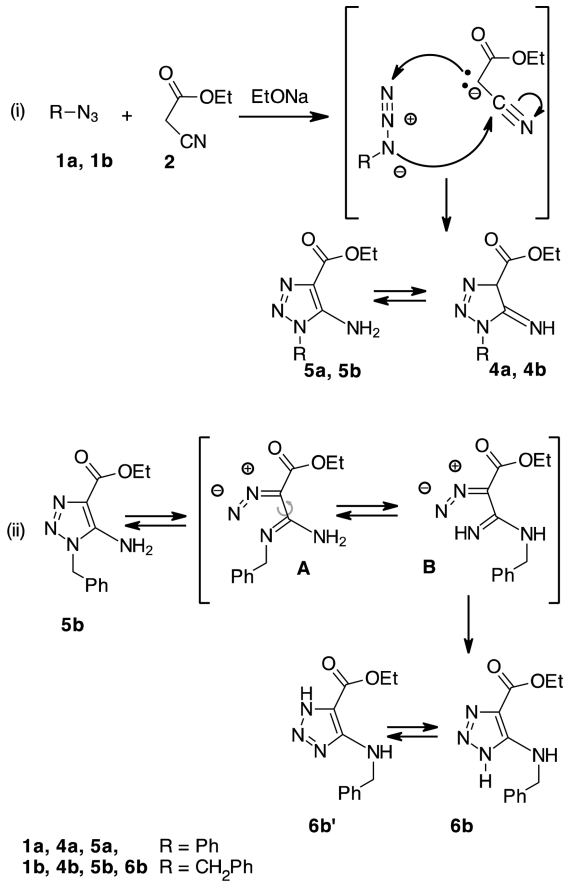
acid with three different points for substituent attachment. While the amino and the carboxylic groups can be used to insert the scaffold into a peptide chain using standard peptide couplings, the substituent in position 1 may be used as a group that mimics the side chain of the dipeptide involved in the turn. Alternatively, with another functional group placed on the chain bonded in position 1, the scaffold can be modeled according to the turn required and/or the reagents employed. Nevertheless, although known since the beginning of the 20th century,[7] the 5-amino-1,2,3-triazole 4 carboxylates have found relatively few applications.[8]

RESULTS AND DISCUSSION

Intrigued by the possibility of using structures as **5a** or **5b** (Scheme 2) for the preparation of triazole-based peptide

Scheme 2



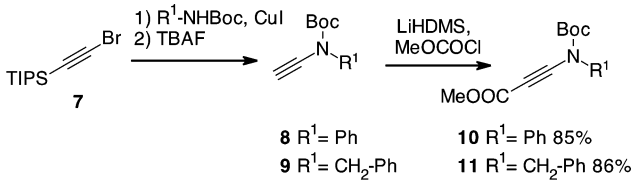
scaffolds, we decided to investigate the synthesis and the reactivity of these aminotriazoles toward standard peptide chemistry. Compounds **5a** and **5b** were prepared following the approach described in the literature[9] reacting phenyl and benzyl azide (**1a** and **1b**, respectively) with ethyl cyanomalonate **2** in the presence of EtONa (Scheme 2 (i)). The malonate anion attacks the terminal nitrogen of the azide, and the more nucleophilic part of the azide reacts with the nitrile to give an imino triazole intermediate (**4a** or **4b**) that immediately tautomerizes to the aromatic ethyl 5-amino-1,2,3-triazole-4-carboxylate (**5a** or **5b**).

While aryl azide **1a**, after 6 h in refluxing ethanol, produced exclusively compound **5a** (65% isolated yield), the benzyl azide **2b** gave a 2:1 mixture of the expected 5-amino-1-benzyl triazole **5b** together with the 5-benzylamino derivative **6b** (Scheme 2 (ii)). This compound was produced by the Dimroth rearrangement,[10] which proceeds through the ring opening at the bond between N1–N2 with formation of a diazo intermediate (**A**, Scheme 2 (ii)) where rotation is now possible. A further cyclization may occur on the less substituted nitrogen with formation of a new 1-NH-triazole **6b** (and its tautomer **6b′**). The Dimroth rearrangement is known to be accelerated by the presence of electron-withdrawing substituents in position 4 of the triazole and by strong acid or basic media. After purification, the two 5-aminotriazoles **5a** and **5b** were submitted to standard peptide bond formation with *N*-CbzAlaOH in the presence of different coupling agents (e.g., DCC, EDC, HATU, DMTMM). Unfortunately, acylation occurred with low yields, and the rearranged compound always contaminated the products.

Since this approach seemed not suitable for an easily functionalization of the 5-amino-1,2,3-triazole-4-carboxylate (as, for example, its introduction in a peptide chain), we decided to explore the possibility to carry out a [3 + 2] cycloaddition between an alky or aryl azide and a N-protected ynamide in order to control the introduction of nitrogen in position 5. This reaction has been described using terminal ynamides carrying a tosyl or an oxazolidinone group on the ynamide nitrogen. The reaction was carried out thermally[11] or under Cu[12] or Ru catalysis,[13] giving simple 4-amido or 5-amido-1,2,3-triazoles, structures on which removal of the substituent on the nitrogen was not easy.

With the idea to exploit the Ru-catalyzed Huisgen cycloaddition for the synthesis of a stable and synthetically versatile analogue of 5-amino-1,2,3-triazole-4-carboxylate, we decided to investigate the cycloaddition of alkyl or aryl azides with methyl *N*-Boc-aminopropiolates **10** and **11** (Scheme 3). These are new

Scheme 3. Preparation of *N*-Boc-ynamides



highly functionalized ynamides equipped with a protected amino group and a carboxylate ester, both moieties suitable for easy tag introduction after the cycloaddition has taken place. Compounds **10** and **11** were prepared by Ullmann-type condensation of *N*-Boc-aniline or *N*-Boc-benzylamine, respectively, with (triisopropylsilyl)bromoacetylene[14] in the presence of catalytic amount of the complex phenanthroline/CuI. The silyl protection was then removed and compounds **8** and **9** were acylated through lithiation with LHMDS followed by reaction with methylchloroformate to give **10** and **11** in 85–86% overall yield (Scheme 3).

When **10** was submitted to cycloaddition with azide **1a** in DMF at rt for 2 h in the presence of $[Cp^*RuCl]_4$ as the catalyst, the corresponding *N*-Boc-5-aminotriazole **12** was isolated in good yield. The cycloaddition produced a single diastereomer as revealed by ^1H and ^{13}C NMR analysis. Analogously, cycloaddition of ynamide **10** with azide **1b** gave triazole **13** in good yield. Following the same synthetic scheme, different azides (**1c–h**, see Table 1) were cyclized to give the corresponding *N*-Boc-5-amino-1,2,3-triazole-4-carboxylates **16–21** in good yields. Also ynamide **11**, in the cycloaddition with azides **1a,b**, gave triazoles **14** and **15**, respectively (Table 1) .

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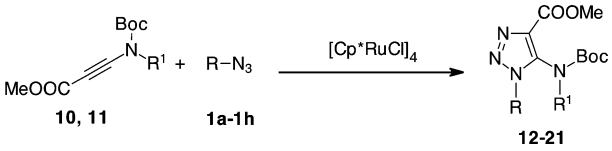
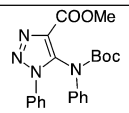
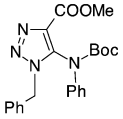
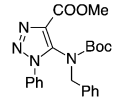
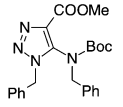
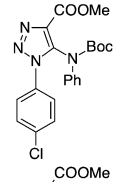
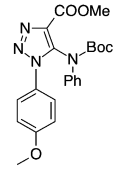
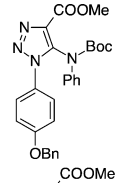
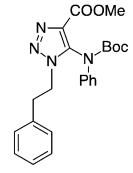
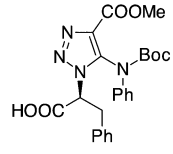
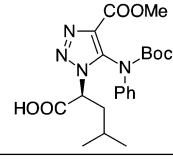
Table 1. Ruthenium Cycloaddition between Methyl *N*-Boc-aminopropiolates 10 and 11 and Azides



10, 11 1a-1h 12-21

Entry	Azide	Ynamide	Product		Yield[a] (%)
1	PhN_3 **1a**	**10**		**12**	86
2	$PhCH_2N_3$ **1b**	**10**		**13**	88
3	PhN_3 **1a**	**11**		**14**	81
4	$PhCH_2N_3$ **1b**	**11**		**15**	90
5	*p*-$ClC_6H_4N_3$ **1c**	**10**		**16**	81
6	*p*-$MeOC_6H_4N_3$ **1d**	**10**		**17**	79
7	p-$OBnC_6H_4N_3$ **1e**	**10**		**18**	83
8	$PhCH_2CH_2N_3$ **1f**	**10**		**19**	88
9	(*S*)-$PhCH_2CH(COOH)N_3$ **1g**	**10**		**20**	86
10	(*S*)-$Me_2CHCH_2CH(COOH)N_3$ **1h**	**10**		**21**	83

[a]Yield of isolated products.

The reaction worked well with aromatic and aliphatic azides and even with α-azido amino acids giving the triazole amino acids **20** and **21** (entries 9 and 10, Table 1) always in good yield and with complete regiocontrol. The regiochemistry presenting the carboxylate in position 4 and the nitrogen in position 5 was postulated on the basis of the orientation proposed in analogous reactions with aryl-substituted ynamides[11] or phenylpropiolate (see below).[15]

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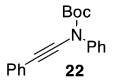
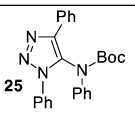
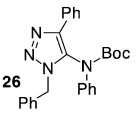
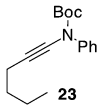
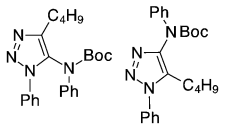
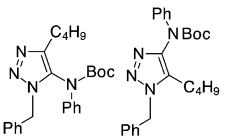
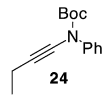
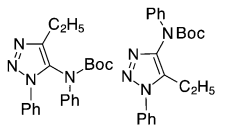
Table 2. Ru-Mediated Cycloaddition of Different Ynamides

entry	Azide	Ynamide[a]	Product	Yield[b] (%)
1	**1a**	 **22**	 **25**	72
2	**1b**	**22**	 **26**	82
3	**1a**	 **23**	 **27a** : **27b** 4 : 1	76[c]
4	**1b**	**23**	 **28a** : **28b** 4 : 1	79[c]
5	**1a**	 **24**	 **29a** : **29b** 3 : 1	73[c]

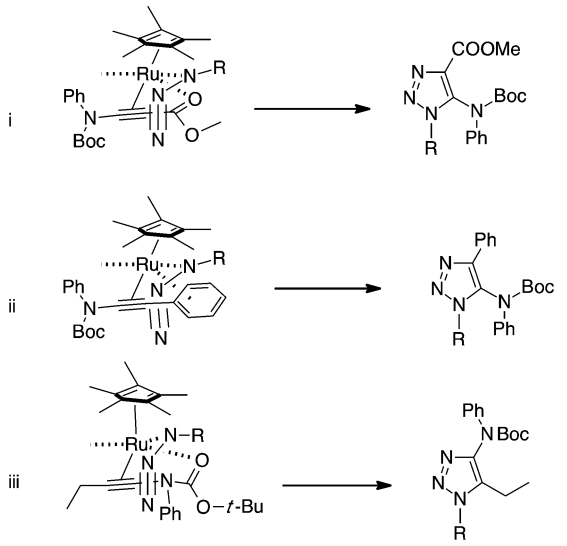
[a]Prepared as described for compound **10**. [b]Yield of isolated compound. [c]Yield relative to the regioisomer mixture.

As the regiochemical control in the cycloaddition was complete and due to the potential applications of the reaction for the synthesis of diverse 5-amino-1,2,3-triazoles, the influence on the regiochemistry of the ynamide C-substituent was investigated (Table 2).

To our surprise, while the regiocontrol was complete also with the phenylethyny derivative **22** (entries 1 and 2 in Table 2), in the presence of an alkyl chain (not too large, as for ynamides **23** and **24**) a mixture of regioisomers was obtained, even though the 5 amino-substituted triazole prevailed (entries 3−5 in Table 2). This last quite unexpected result[16] suggests that probably the high regiocontrol observed with ynamides **10**, **11**, and **22** may be explained by a possible additional interaction between the Ru atom and the full nonbonding orbitals of the carboxymethyl group (for **10** and **11**) or the π aromatic orbitals of the phenyl in compound **22** (Scheme 4).[11] In the absence of these effects, the interaction of Ru with the *N*-Boc-aminoaryl substituent drives the orientation toward the opposite regioisomers (as **27b**−**29b** in Table 2).

To explore the synthetic potential and the scope of the reaction, a general functionalization around the triazole ring was explored. The carboxymethyl group in position 4 of triazole **12** was directly transformed into amide by displacement with a primary amine such as allylamine or benzylamine giving compounds **30** and **31** in 75 and 69% yield, respectively. Alternatively, the hydrolysis of the ester in position 4 of **12** or **14** produced the carboxylic acids that were further transformed into the corresponding acyl chlorides (Scheme 5).

Scheme 4. Proposed Intermediates for the Different Regiochemical Outcomes[a]



[a]Parts i and ii justify the selectivity toward the 5-amino-substituted triazole; iii justifies the formation of the 4-amino-substituted triazole in the reaction with alkyl *N*-Boc-ynamides.

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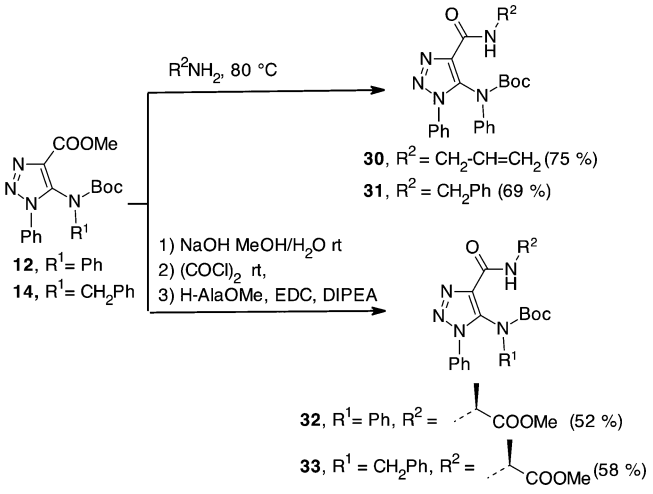
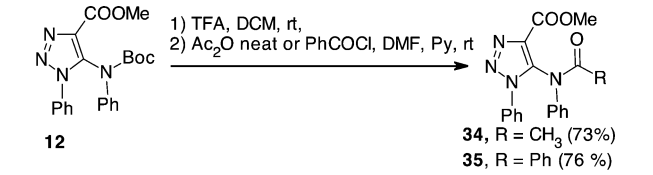
Scheme 5. Functionalization at Position 4



The further coupling with (*S*)-alanine methyl ester mediated by DIPEA and DMAP in DMF gave triazole dipeptides **32** and **33**, respectively, in 52 and 58% isolated yield.[17]

The functionalization in position 5 of triazole passed through the removal of Boc that was accomplished with TFA (Scheme 6).

Scheme 6. Functionalization at Position 5

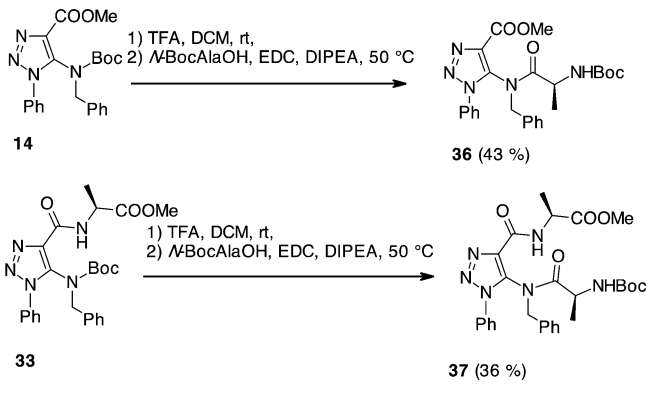


Unfortunately, the aniline-type NH in position 4 of the product derived from **12** was a poor nucleophile as it reacted exclusively with acetic anhydride or benzoyl chloride to yield compounds **34** and **35** in acceptable yields.

The reaction between the deprotected 5-aminotriazoles and different carboxylic acids using the most common peptide-coupling agents (DCC, EDC HATU, PyBOP) was also attempted. Starting from the *N*-benzyl derivative **14** and subsequent TFA-mediated Boc removal, EDC coupling with *N*-Boc-protected alanine methyl ester gave product **36** in moderate yield (Scheme 7).

Analogously, starting from compound **33**, removal of the Boc and further EDC-mediated coupling with (*S*)- alanine methyl ester gave the triazole-containing dipeptide **37** in 36% yield (Scheme 7).

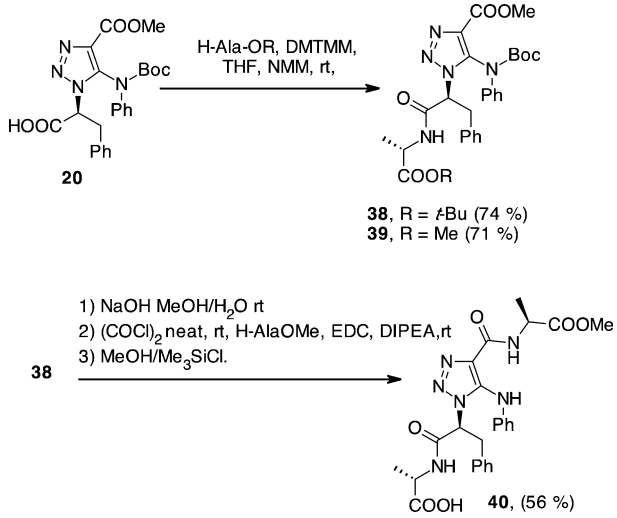
Scheme 7. Preparation of Triazole-Based Peptides



The enantiomeric integrity of products **20**, **21**, **32**, **33**, and **36** was determined by HPLC analysis on a chiral column in comparison with the chromatograms recorded with the coupling products obtained from the racemic amino acids.

Finally, the carboxylic group of the α-azido acids inserted in position 1 of the triazole (compound **20**) was reacted with L-alanine *tert*-butyl or methyl esters in the presence of DMTMM[18] as the coupling agent to generate the triazole-containing peptides **38** and **39** (Scheme 8).

Scheme 8. Preparation of Triazole-Based Dipeptide



Elongation of the peptide could be possible by methyl ester hydrolysis of **38** followed by EDC-mediated coupling with (*S*)-alanine methyl ester. Final treatment with HCl in MeOH removed the Boc and the *tert*-butyl protections to yield the triazole containing (inverted) peptide **40**. In all of the cases described above, formation of products derived from the Dimroth rearrangement was never observed. This is a remarkable result especially regarding products having an alkyl group in position 1 that, coupled with an electron-withdrawing group in position 4, is known to promote this rearrangement.[19] Compound **39** crystallized on standing in H_2O to give crystals that were submitted to X-ray analysis, confirming the stereochemistry outcome of the cycloaddition (Supporting Information).

To investigate the suitability of aminotriazole scaffold to mimic peptides, with particular reference to reverse turns, comparison of derivative **39** with this structural element was made in detail. Our molecular prototype was subjected to thorough computational analysis of its conformational properties by molecular mechanics (MM), quantum mechanics (QM), and molecular dynamics (MD). The conformational analysis showed that **39** has some populated conformers satisfying reverse turn requirements. In particular, two geometries have a β value much smaller than $\pm 90°$ and a $d_\alpha < 7$ Å. Moreover, one of the two most stable conformers shows the CO−HN H-bond typical of β turns. In addition, a trial-and-error type approach to classify β-turn type was attempted, based on the atom-by-atom superposition of the two conformers onto a built-on-purpose template. This method suggested a type I′ β-turn reference frame for one conformer and a V′ β-turn reference for the other. The superposition of both

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lowest energy conformers of **39** onto, respectively, standard type I′ and standard type V′ β-turns, are shown in Figure 1 and 2,

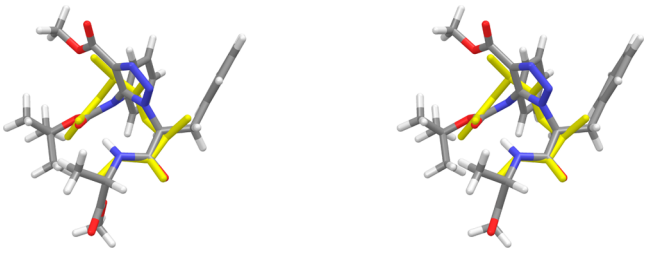


Figure 1. Conformer of **39** colored by atom types (crossed stereoview), superimposed with standard type-I′ β-turn (yellow structure with omitted hydrogen atoms).

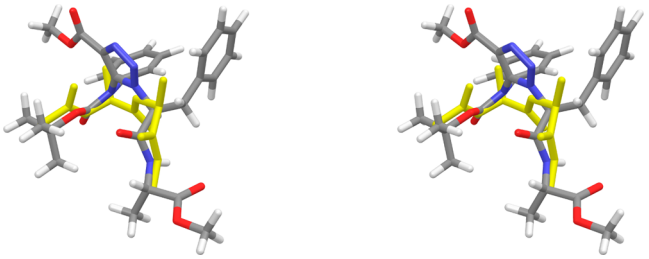


Figure 2. Conformer of **39** colored by atom types (crossed stereoview), superimposed with a standard type-V′ β-turn (yellow structure with omitted hydrogen atoms).

confirming, as outlined by the X-ray data, that compound **39** can be considered as a good candidate to mimic a reverse turn. A more detailed explanation of the molecular modeling study is reported in the Supporting Information.

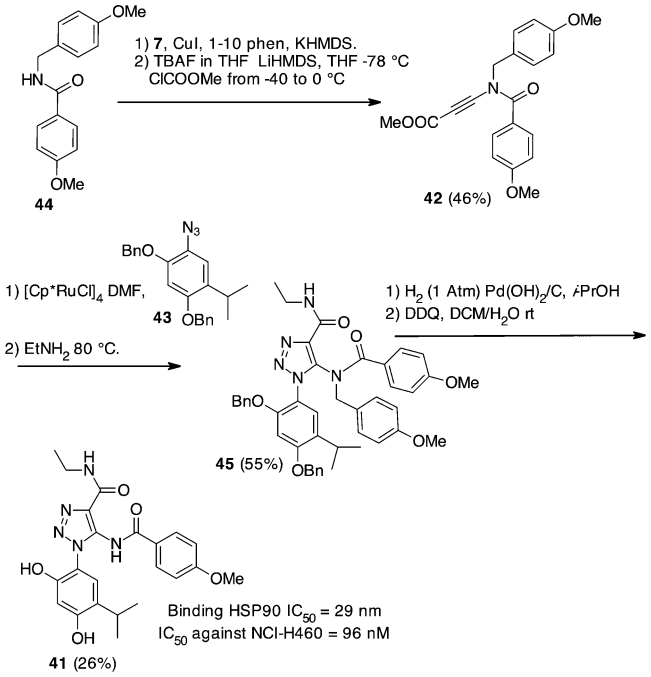
The 5-amino-1,2,3-triazole carboxylates can also find interesting applications as scaffolds for the preparation of bioactive compounds in medicinal chemistry. Based on a recent report that points out how substituted amidoisoxazole or -triazole carboxylates can be employed in HSP90 binding,[20] we prepared 5-amido-4-carboxytriazole **41** through Ru-mediated cycloaddition of the cumenediol azide **43**[20b] and the ynamido propiolate **42**.

This product was prepared by Ullmann-type reaction of amide **44** with TIPS-bromoacetylene **7** followed by deprotection and carboxylation with LiHMDS and methyl chloroformate (Scheme 9). Ru-mediated cycloaddition between **42** and **43** gave the triazole carboxylate that was transformed into amide by reaction with ethylamine and further deprotected first using H_2 on $Pd(OH)_2/C$ to remove the benzyl groups and then with DDQ in DCM/H_2O to remove the *p*-methoxybenzoyl protecting group to give amidotriazole **41** in 26% yield. Compound **41** was submitted to a binding text with HSP90 determined by a fluorescence polarization assay (FP Assay) to give an IC_{50} of 29 ± 4 nM (mean value with $n = 4$). Cytotoxicity on NCI-H460 non-small cell lung carcinoma cells confirmed a promising IC_{50} value of 96 ± 2 nM ($n = 4$).

CONCLUSION

In conclusion, we have developed a regiocontrolled synthesis of 5-amino-trisubstitued triazoles via Ru mediated cycloaddition of ynamides and azides. The regiocontrol of the reaction was possible only if a group able to interact with the Ru catalyst were present on the other side of the triple bond with respect to the ynamide moiety. This is an efficient example of the possibility to

Scheme 9. Preparation of a Triazole-Based HSP90 Inhibitor



control the regiochemistry of the addition based on the substrate/catalyst structure. This procedure avoids the event of the Dimroth rearrangement that may give different (and sometimes unpredictable) substituted triazoles. The *N*-Boc-5-aminotriazoles were transformed into the trifluoroacetates after deprotection and reacted as their free amine during the coupling. The reaction products can be used as stereodefined scaffolds for the preparation of triazole-containing peptidomimetics or as generic scaffolds for the preparation of diverse trisubstituted amino triazoles. The procedure can be also applied to the preparation of triazoles containing a substituent arrangement suitable for producing antitumor compounds based on HSP90 inhibition.

EXPERIMENTAL SECTION

General Methods. All reagents were used as purchased from commercial suppliers without further purification. The reactions were carried out in oven-dried or -flamed vessels and performed under nitrogen. Solvents were dried and purified by conventional methods prior use. Flash column chromatography was performed with silica gel 60, 0.040−0.063 mm (230−400 mesh). Aluminum-backed plates precoated with silica gel 60 (UV254) were used for thin-layer chromatography and were visualized by staining with $KMnO_4$. NMR spectra were recorded under conditions that are specified for each spectrum (temperature 25 °C unless specified). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad. Chemical shifts (δ) are given in ppm relative to the resonance of their respective residual solvent peak, $CHCl_3$ (7.27 ppm, 1H; 77.16 ppm, the middle peak, ^{13}C). High- and low-resolution mass spectroscopy analyses were recorded at 70 eV by electrospray ionization using a triple quadrupole mass spectrometer. Melting points were determined in open capillary tubes and are uncorrected. Specific rotations were measured with a 10 cm cell with a Na 589 nm filter: values are given in 10^{-1} deg·cm^3·g^{-1}.

L-Phenyl-4-carbethoxy-5-amino-l,2,3-triazole (5a). Compound **5a** was prepared following the general procedure previously described.[9a] The product was isolated by crystallization from petroleum ether 40−60 °C: mp 125−127 °C (lit.[21] mp 125−126 °C); ^1H NMR (400 MHz, $CDCl_3$) δ 7.81−7.31 (m, 5H), 6.50 (bs, 2H), 4.15 (m, 2H), 1.30 (m,

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3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.3, 60.0, 114.7, 122.9, 127.5, 128.7, 128.7, 137.1, 147.2, 159.6.

1-Benzyl-4-carbethoxy-5-amino-l,2,3-triazole (5b). Compound **5b** was prepared following the general procedure described for **5a**. The product was isolated by crystallization from petroleum ether 40−60 °C: mp 153−153 °C (lit.[9a] mp 152−154 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54−6.95 (m, 5H), 6.38 (bs, 2H), 5.24−4.78 (m, 2H), 4.15 (m, 2H), 1.30 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.3, 51.9, 61.0, 112.8, 125.6, 128.7, 129.2, 129.4, 135.4, 148.7, 165.6.

Methyl *N*-Phenyl-*N*-Boc-3-aminopropiolate (10). Compound **8** (434 mg, 2 mmol, prepared as described in ref 14) was dissolved in dry THF (10 mL) under nitrogen; the solution was cooled to −78 °C, and LiHMDS (3.5 μL of a solution 1 M in THF, 3.5 mmol) was added. The mixture was slowly warmed to −40 °C and maintained at this temperature for 1 h. The solution was transferred via cannula to a flask containing methyl chloroformate (620 mg μL, 6.5 mmol) in THF (6 mL) at −40 °C, and the solution was warmed to room temperature. Saturated aqueous NH_4Cl (10 mL) and EtOAc (10 mL) were added, and the organic phase was extracted (3 × 15 mL EtOAc) and dried over Na_2SO_4. The title compound was obtained after purification by column chromatography (petroleum ether 40−60/EtOAc from 80:20 to 75:25) (467 mg, 85%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48−7.12 (m, 5H), 3.71 (s, 3H), 1.50 (s, 9H); ^{13}CNMR (101 MHz, $CDCl_3$) δ 154.4, 151.5, 137.4, 128.7 (2C), 127.2 (2C), 124.5, 84.6, 82.5, 65.3, 51.86, 27.3 (3); HRMS (ESI) m/z calcd for $C_{15}H_{17}NO_4Na^+$ 298.1055, found 298.1050.

Methyl *N*-Phenyl-*N*-Boc-3-aminopropiolate (11). Column chromatography (petroleum ether 40−60/EtOAc from 80:20 to 75:25) gave compound **11** (497 mg, 86%) as an oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53−7.18 (m, 5H), 4.24 (s, 2H), 3.71 (s, 3H), 1.51 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 154.4, 151.5, 137.4, 128.8 (2C), 127.3 (2C), 124.5, 84.6, 82.6, 65.3, 60.8, 51.8, 27.3 (3C); HRMS (ESI) m/z calcd for $C_{16}H_{19}NO_4Na^+$ 312.1212, found 312.1206.

Methyl 1-Phenyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 12, General Procedure. To phenyl azide **1a** (120 mg, 1 mmol) dissolved in dry DMF (2.5 mL) at rt was added compound **10** (275 mg, 1 mmol). The flask was subjected to three vacuum−nitrogen cycles, then $(Cp^*RuCl)_4$ (49 mg, 0.045 mmol) was added followed other three vacuum−nitrogen cycles. The reaction was stirred at room temperature until completion (monitored by TLC, 2 h). EtOAc (10 mL) and water (5 mL) were then added. The organic phase was extracted four times with EtOAc (5 mL each), washed with water (2 mL, three times) and brine (5 mL, one time), and dried over Na_2SO_4; the solvent was removed, and the mixture was purified by column chromatography (petroleum ether 40−60/EtOAc 60:40). The title compound was obtained as a purple oil with a tendency to solidify on standing (339 mg, 86%). An analytical sample was crystallized two times from EtOH/H_2O: mp 123−126 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52−6.99 (m, 8H), 6.90 (dm, 2H), 3.87 (s, 3H), 1.29 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.8, 138.9, 134.3, 132.9, 129.9 (2C), 129.18 (2C), 128.4 (2C), 126.3 (2C), 124.8 (2C), 123.9, 122.5, 82.9, 51.7, 27.4 (3C); ESI/MS (M + Na)$^+$ 417. Anal. Calcd for $C_{21}H_{22}N_4O_4$: C, 63.95; H, 5.62; N, 14.20; O, 16.23. Found: C, 63.89; H, 5.65; N, 14.17.

Methyl 1-Benzyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 13. Column chromatography (petroleum ether 40−60/EtOAc 60:40) gave compound **13** (359 mg, 88%) as a waxy material. An analytical sample was crystallized from *i*-PrOH: mp 113−115 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−6.89 (m, 10H), 5.44 (bs, 1H), 4.88 (bs, 1H), 3.87 (s, 3H), 1.18 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ = 167.6, 159.9, 150.8, 138.7, 138.1, 133.9, 133.0, 128.7 (2C), 128.4 (2C), 127.2 (2C), 126.1, 124.3 (2C), 82.7, 51.7, 51.3, 27.2 (3C); ESI/MS (M + Na)$^+$ 431. Anal. Calcd for $C_{22}H_{24}N_4O_4$ C, 64.69; H, 5.92; N, 13.72; O, 15.67. Found: C, 64.62; H. 5.94; N, 13.70.

Methyl 1-Phenyl-5-(*N*-benzyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 14. Column chromatography (petroleum ether 40−60/EtOAc 50:50) gave compound **14** (331 mg, 81%) as a dense oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62−6.57 (m, 10H), 4.75 (d, J = 14.2 Hz, 1H), 4.48 (d, J = 14.3 Hz, 1H), 3.89 (s, 3H), 1.28 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.9, 152.5, 134.3, 129.3 (2C), 129.0 (2C), 128.8 (2C), 128.0 (2C), 127.7 (2C), 124.4, 123.6 (2C), 82.3, 52.4, 51.7, 27.5 (3C); HRMS (ESI) m/z calcd for $C_{22}H_{24}N_4O_4Na^+$ 431.1695, found 431.1690.

Methyl 1-Benzyl-5-(*N*-benzyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 15. Column chromatography (petroleum ether 40−60/EtOAc 65:45) gave compound **15** (380 mg, 90%) as a waxy material. An analytical sample was crystallized from EtOH/H_2O: mp 127−129 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−6.83 (m, 10H), 4.99 (m 2H), 4.40 (m, 2H), 3.82 (s, 3H), 1.09 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.0, 152.8, 139.4, 135.4, 133.1, 132.2, 129.1 (2C), 128.4 (2C), 128.3 (2C), 128.0 (3C), 127.6, 81.9, 52.8, 51.6, 50.4, 27.2 (3C); ESI/MS (M + Na)$^+$ 445. Anal. Calcd for $C_{23}H_{26}N_4O_4$ C, 65.39; H, 6.20; N, 13.26; O, 15.15. Found: C, 65.34; H, 6.22; N, 13.24.

Methyl 1-*p*-Chlorophenyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 16. Column chromatography (petroleum ether 40−60/EtOAc 65:45) gave compound **16** (346 mg, 81%) as a waxy material. An analytical sample was crystallized from EtOH/H_2O: mp 117−119 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.69 (m 2H), 7.45 (m, 4H), 7.33−7.10 (m, 2H), 7.03−6.96 (m, 1H), 3.31 (s, 3H), 1.31 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.1, 151.9, 139.7, 138.7, 136.6 (2C), 134.1, 133.4 (2C), 131.4 (2C), 129.2 (2C), 126.7, 125.8, 125.4, 83.8, 50.8, 28.1 (3C); ESI/MS (M + Na)$^+$. 451 Anal. Calcd for $C_{21}H_{21}ClN_4O_4$: C, 58.81; H, 4.94; N, 13.06; O, 14.92; Cl, 8.27. Found: C, 58.77; H, 4.97; N, 13.04.

Methyl 1-*p*-Methoxyphenyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 17. Column chromatography (petroleum ether 40−60/EtOAc 65:45) gave compound **17** (334 mg, 79%) as a dense oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.41−6.67 (m, 9H), 3.80 (s 3H), 3.30 (s, 3H), 1.45−1.20 (m, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 161.1, 160.2, 148.7, 139.7, 139.6, 133.8, 129.4 (2C), 129.1 (2C), 126.8 (2C), 126.1, 125.4, 114.9 (2C), 83.4, 55.9, 53.3, 28.2 (3C); HRMS (ESI) m/z calcd for $C_{22}H_{24}N_4O_5Na^+$ 447.1645, found 447.1643.

Methyl 1-*p*-Benzyloxyphenyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 18. Column chromatography (petroleum ether 40−60/EtOAc 65:45) gave compound **18** (465 mg, 93%) as a red waxy material. An analytical sample was crystallized from EtOH/H_2O: mp 105−107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−6.69 (m, 14H), 4.75 (d, J = 14.3 Hz, 1H), 4.48 (d, J = 14.3 Hz, 1H), 3.89 (s, 3H), 1.38−1.07 (m, 9H); ^{13}C NMR (101 MHz, DMSO-d) δ 160.3, 151.7, 149.2, 134.7, 133.1, 129.3 (4C), 129.1 (4C), 128.9 (3C), 128.7 (4C), 124.8 (2C), 83.9, 52.1, 50.5, 28.0 (3C); ESI/MS (M + Na). Anal. Calcd for $C_{28}H_{28}N_4O_5$: C, 67.19; H, 5.64; N, 11.19; O, 15.98. Found: C, 67.14; H, 5.61; N, 11.16.

Methyl 1-Phenethyl-5-(*N*-phenyl-*tert*-butoxycarbonylamino)-1*H*-1,2,3-triazole-4-carboxylate 19. Column chromatography (petroleum ether 40−60/EtOAc 65:45) gave compound **19** (371 mg, 88%) as a dense oil: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.37−6.93 (m, 10H), 4.33−4.17 (m, 4H), 3.29 (s, 3H), 1.41 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.3, 152.0, 139.3, 136.7, 134.0, 129.6 (2C), 129.1 (2C), 129.0 (2C), 128.1, 128.0, 127.0, 126.6, 125.3, 83.5, 61.5, 50.5, 34.5, 28.1 (3C); HRMS (ESI) m/z calcd for $C_{23}H_{26}N_4O_4Na^+$ 445.1852, found 445.1849.

(*S*)-2-(5-(*tert*-Butoxycarbonyl(phenyl)amino)-4-(methoxycarbonyl)-1*H*-1,2,3-triazol-1-yl)-3-phenylpropanoic Acid 20. Column chromatography (petroleum ether 40−60/EtOAc from 15:85 to 0:100) gave compound **20** (400 mg, 86%) as a dense oil. An analytical sample was obtained by crystallization of the dimethylamine salt in acetone: $[\alpha]^{21}_D$ (of dimethylamine salt) = −9.96 (c = 0.67 in MeOH/H_2O 1/1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (bs, 1H), 7.54−6.83 (m, 10H), 4.86 (bs, 1H), 3.88 (s, 3H), 2.41 (m, 1H), 2.02−1.84 (m, 1H), 1.33 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.2, 164.0, 160.4, 160.3, 160.0, 151.7, 151.7, 138.9, 138.7, 128.2 (2C), 128.1 (2C), 126.8 (2C), 126.6 (2C), 124.8, 82.7, 51.0, 36.6, 27.5 (3C); ESI/MS (M − H)$^-$ 449. Anal. Calcd for $C_{26}H_{33}N_5O_6$ (dimethylamine salt): C, 61.04; H, 6.50; N, 13.69; O, 18.77. Found: C, 60.99; H, 6.53; N, 13.73.

(*S*)-2-(5-(*tert*-Butoxycarbonyl(phenyl)amino)-4-(methoxycarbonyl)-1*H*-1,2,3-triazol-1-yl)-4-methylpentanoic Acid 21. Column chromatography (petroleum ether 40−60/EtOAc from 15:85 to 0:100) gave compound **21** (358 mg, 83%) as a dense oil. An analytical

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sample was obtained by crystallization of the dimethylamine salt in acetone: $[\alpha]^{21}_D$ (of dimethylamine salt) = −13.66 (c = 0.86 in MeOH/H_2O 1/1); ^{1}H NMR (400 MHz,$CDCl_3$) δ 7.73 (t, J = 7.6 Hz, 2H), 7.50−7.12 (m, 3H), 4.64 (m, 1H), 3.95 (s, 3H), 2.40 (m 1H), 2.34−2.06 (m, 2H), 1.58 (s, 9H), 0.95 (d, J = 5.6 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.7, 150.7, 139.1, 138.4, 133.0, 128.5, 128.4 (2C), 127.9, 127.7, 127.2 (2C), 83.3, 62.5, 56.2, 51.2, 39.8, 25.2 (3C), 18.5; ESI/MS (M − H) 431. Anal. Calcd for $C_{23}H_{35}N_5O_6$ (dimethylamine salt): C, 57.85; H, 7.39; N, 14.67; O, 0.10. Found: C, 57.80; H, 7.42; N, 14.71.

***tert*-Butyl (1,4-Diphenyl-1*H*-1,2,3-triazol-5-yl)-phenylcarbamate 25.** Column chromatography (petroleum ether 40−60/EtOAc 70:30) gave compound **24** (297 mg, 72%) as a dense oil with a tendency to solidify on standing. An analytical sample was obtained by crystallization from *i*-PrOH: mp 154−156 °C (dec); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (m, 3H), 7.64−6.76 (m, 12H), 1.23 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.6, 140.9, 139.2, 134.9, 133.7, 129.3, 129.0, 128.4 (2C), 128.1 (2C), 125.5 (6C), 125.4 (2C), 123.9 (2C), 123.2 (2C), 82.8, 27.3; ESI/MS (M + Na)$^+$ 435. Anal. Calcd for $C_{25}H_{24}N_4O_2$: C, 72.80; H, 5.86; N, 13.58; O, 7.76. Found: C, 72.77; H, 5.88; N, 13.56.

***tert*-Butyl (1-Benzyl-4-phenyl-1*H*-1,2,3-triazol-5-yl)-phenylcarbamate 26.** Column chromatography (petroleum ether 40−60/EtOAc 70:30) gave compound **26** (349 mg, 82%) as a dense oil with a tendency to solidify on standing. An analytical sample was obtained by crystallyzation from *i*-PrOH: mp 168 °C (dec); ^{1}H NMR (400 MHz $CDCl_3$) δ 8.20−6.83 (m, 15H), 5.47 (d, J = 10.2 Hz, 1H), 4.77 (d, J = 10.2 Hz, 1H), 0.94 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.8, 141.7, 138.6, 133.7, 129.1, 128.8 (2C), 128.5 (2C), 128.3 (2C), 128.0, 127.9 (2C), 127.2 (2C), 125.4, 125.0 (2C), 122.8 (2C), 82.4 51.2, 26.9 (3C); ESI/MS (M + Na) 449. Anal. Calcd for $C_{26}H_{26}N_4O_2$: C, 73.22; H, 6.14; N, 13.14; O, 7.50. Found: C, 73.18; H, 6.17; N, 13.12.

***tert*-Butyl (4-Butyl-1-phenyl-1*H*-1,2,3-triazol-5-yl)-phenylcarbamate 27a.** Column chromatography (petroleum ether 40−60/EtOAc 70:30) gave compound **27** (298 mg, 76%) as a mixture of isomers. The ratio was determined by ^{1}H NMR. A second column chromatography with petroleum ether 40−60/EtOAc from 100:0 to 80:20 allowed the isolation of pure **27a** as a dense oil: ^{1}H NMR (400 MHz $CDCl_3$) δ 7.60−6.90 (m, 10H), 2.62−2.49 (m, 1H), 2.49−2.34 (m, 1H), 1.39−1.25 (m, 3H), 1.17 (s, 10 H), 0.83 (t, J = 7.3 Hz, 3H); ^{13}C NMR (101 MHz $CDCl_3$) δ 153.2, 143.7, 141.1, 136.3, 132.7, 129.3, 129.1, 128.3 (2C), 125.7 (2C), 125.5 (2C), 124.9 (2C), 81.4, 28.9, 27.7 (3C), 22.2, 21.9, 13.0; HRMS (ESI) m/z calcd for $C_{23}H_{28}N_4O_2Na^+$ 415.2110, found 415.2116.

***tert*-Butyl (4-Butyl-1-benzyl-1*H*-1,2,3-triazol-5-yl)-phenylcarbamate 28a.** Column chromatography (petroleum ether 40−60/EtOAc 70:30) gave compound **28** (320 mg, 79%) as a mixture of isomers. The ratio was determined by ^{1}H NMR. A second column chromatography with petroleum ether 40−60/EtOAc from 100:0 to 80:20 allowed the isolation of pure **28a** as a dense oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67−6.67 (m, 10H), 5.33 (d, J = 15.2 Hz, 1H), 4.94 (d, J = 15.2 Hz, 1H), 2.49 (m, 2H), 1.78−1.52 (m, 2H), 1.41−1.17 (m, 11H), 0.86 (t, J = 7.4 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.3, 143.0, 139.2, 133.9, 132.2, 128.4 (3C), 128.3, 127.8 (2C), 127.3, 125.3 (2C), 123.5, 82.3, 51.2, 29.8, 27.3 (2C), 24.0, 22.2, 13.3; HRMS (ESI) m/z calcd for $C_{24}H_{30}N_4O_2Na^+$ 429.2267, found 429.2263.

***tert*-Butyl (4-Ethyl-1-phenyl-1*H*-1,2,3-triazol-5-yl)-phenylcarbamate 29a.** Column chromatography (petroleum ether 40−60/EtOAc 70:30) gave compound **29** (266 mg, 73%) as a mixture of isomers. The ratio was determined by ^{1}H NMR. A second column chromatography with petroleum ether 40−60/EtOAc from 100:0 to 80:20 allowed the isolation of pure **29a** as a dense oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43−7.36 (m, 7H), 7.17−7.13 (m, 3H), 2.86−2.73 (t-like, 2H), 1.38 (s, 9H), 0.93 (t, J = 7.7 Hz, 3H); ^{13}C NMR (101 MHz,) δ 154.6, 143.0, 140.6, 135.6, 129.2, 128.5 (2C), 127.9 (2C), 127.8 (2C), 125.3 (2C), 124.7 (2C), 81.1, 30.3, 28.0(3C), 11.9; HRMS (ESI) m/z calcd for $C_{21}H_{24}N_4O_2Na^+$ 387.1797, found 387.1793.

***tert*-Butyl [4-[(Allylamino)carbonyl]-1-phenyl-1*H*-1,2,3-triazol-5-yl]phenylcarbamate 30.** Allylamine (142 mg, 2.5 mmol) was added to compound **12** (100 mg, 0.25 mmol) dissolved in dry MeOH (0.5 mL), and the mixture was heated for 6 h at 80 °C in a sealed tube. The solvent and the excess of the amine were removed under reduced pressure and the residue was crystallized from MeOH/H_2O to give compound **30** (83 mg, 80%): mp 186−187 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69−6.90 (m, 11H), 6.06−5.77 (m, 1H), 5.35−5.07 (m, 2H), 4.07 (d, J = 14.0 Hz, 2H), 1.34 (s, 9H); ^{13}C NMR (101 MHz $CDCl_3$) δ 158.6 (2C), 134.5, 133.5, 129.9, 129.8 (2C), 129.3, 129.3 (2C), 129.1, 128.4, 128.4, 128.3, 126.4, 125.5, 124.1, 116.2, 82.7, 40.87 27.5 (3C); ESI/MS (M + Na) 442. Anal. Calcd for $C_{23}H_{25}N_5O_3$: C, 65.85; H, 6.01; N, 16.70; O, 11.44. Found: C, 65.81; H, 6.04; N, 16.68.

***tert*-Butyl [4-[(Benzylamino)carbonyl]-1-phenyl-1*H*-1,2,3-triazol-5-yl]phenylcarbamate 31.** Starting from **14** and following the same procedure described for **30**, compound **31** was crystallized from MeOH/H_2O (95 mg, 81%): mp 202 °C (dec); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (m, 2H), 7.64−7.10 (m, 13H), 5.48 (d, J = 15.2 Hz, 1H), 4.78 (d, J = 15.3 Hz, 1H), 0.93 (s, 10H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.8, 141.7, 138.6, 133.8, 132.5, 129.8, 129.2, 128.9 (2C), 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.2, 125.4, 125.0 (2C), 122.9, 122.8, 82.4, 51.2, 51.2, 26.9 (3C); ESI/MS (M + Na) 492. Anal. Calcd for $C_{27}H_{27}N_5O_3$: C, 69.07; H, 5.80; N, 14.92; O, 10.22. Found: C, 69.01; H, 5.83; N, 14.90.

Methyl *N*-([5-[(*tert*-Butoxycarbonyl)(phenyl)amino]-1-phenyl-1*H*-1,2,3-triazol-4-yl]carbonyl)-L-alaninate 32, General Procedure. Compound **12** (100 mg, 0.25 mmol) was dissolved in MeOH (0.5 mL) and the solution added to 2 mL of a 1 M solution of NaOH at rt. The solution was stirred for 2 h, then cooled to 0 °C, and 3 mL of a 1 M solution of HCl was added. EtOAc (10 mL) was then added, and the organic phase was separated and dried over anhydrous Na_2SO_4. The solvent was evaporated, the residue taken in dry toluene (5 mL), and the solvent evaporated under reduced pressure in order to dry the product. Oxalyl chloride (2 mL) was added and the solution stirred at rt for 3 h. The liquid phase was removed under vacuum (10 mmHg) and the residue dissolved in dry CH_2Cl_2 (0.5 mL). This solution was added to a solution containing H-AlaOMe (41 mg, 0.4 mmol), DIPEA (0.39 mL, 2.5 mmol), and DMAP (5 mg) in dry CH_2Cl_2 (1 mL). The solution was stirred at rt for 6 h, then CH_2Cl_2 (10 mL) was added, and the organic phase was washed with a solution of HCl 1 M, (2 × 4 mL), $NaHCO_3$ 1 M (2 × 25 mL), water (2 mL), and brine (15 mL). The organic phase was separated and dried over anhydrous Na_2SO_4 and the solvent evaporated. Column chromatography (petroleum ether 40−60/EtOAc from 40:60 to 0:100) gave compound **32** (60 mg, 52%) as a waxy material: $[\alpha]^{21}_D$ = −15.36 (c = 0.5 in $CDCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51−7.33 (m, 6H), 7.23−7.04 (m, 4H), 6.63 (d, J = 7.9 Hz, 1H), 4.76 (m, 1H), 3.74 (s, 3H), 1.53 (d, J = 7.1 Hz, 3H), 1.34 (s, 9H); ^{13}C NMR (101 MHz $CDCl_3$) δ 172.5, 161.7, 141.3, 139.2, 135.7, 134.5, 129.8, 129.2, 128.4 (4C), 126.4, 126.3, 125.5, 124.1, 123.4, 122.7, 120.1, 120.1, 82.6, 52.1, 47.3, 27.56 (3C), 17.9; HRMS (ESI): m/z calcd for $C_{24}H_{27}N_5O_5Na^+$ 488.1910, found 488.1906

Methyl *N*-([5-[(*tert*-Butoxycarbonyl)(phenyl)amino]-1-benzyl-1*H*-1,2,3-triazol-4-yl]carbonyl)-L-alaninate 33. Starting from **14** and following the same procedure described for **32,** column chromatography (petroleum ether 40−60/EtOAc from 40:60 to 0:100) gave compound **33** (67 mg, 58%) as a waxy material: $[\alpha]^{21}_D$ = −17.67 (c = 0.5 in $CDCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.85 (s, 1H), 7.83−6.92 (m, 10H), 5.16 (s, 2H), 4.75 (q, J = 6.7 Hz, 1H), 3.77 (s, 3H), 1.44 (s and d, 12H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.8, 158.0, 149.1, 144.3, 137.6, 135.1, 129.2, 128.5, 128.3 (2C), 127.9 (2C), 127.8 (2C), 127.3 (2C), 119.8, 81.2, 52.1, 50.7, 49.9, 27.8 (3), 19.8; HRMS (ESI) m/z calcd for $C_{25}H_{29}N_5O_5Na^+$ 502.2067, found 502.2064

Methyl 5-[Acetyl(phenyl)amino]-1-phenyl-1*H*-1,2,3-triazole-4-carboxylate 34. Trifluoaroacetic acid (0.16 mL, 2 mmol) was added to a solution of **12** (120 mg, 0.3 mmol) in CH_2Cl_2 (2 mL) at 0 °C. The solution was stirred at this temperature for 20 min and then warmed to room temperature and stirred for 4 h. The TFA was removed under vacuum, and to the residue were added acetic anhydride (1 mL) and AcONa (0.1 g), and the solution was stirred at rt overnight. The reaction was quenched with 3 mL of a 1 M solution of HCl and extracted with CH_2Cl_2 (10 mL × 3). The organic solution was then dried over anhydrous Na_2SO_4 and concentrated under vacuum. The residue was purified by flash column chromatography on (petroleum ether 40−60/EtOAc 80:20) to give compound **34** (74 mg, 73%). An analytical sample

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was crystallized from EtOH/H_2O: mp 123−124 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61−6.98 (m, 8H), 6.81 (d, J = 7.4 Hz, 2H), 3.96 (s, 3H), 1.99 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.8, 160.3, 139.5, 134.0, 130.3, 130.3, 129.8(2C), 129.2(2C), 129.0(2C), 128.6, 127.1, 124.9, 115.9, 53.8, 51.8; ESI/MS (M + Na) 359. Anal. Calcd for $C_{18}H_{16}N_4O_3$: C, 64.28; H, 4.79; N, 16.66; O, 14.27. Found: C, 64.24; H, 4.81; N, 16.64.

Methyl 5-[Benzoyl(phenyl)amino]-1-phenyl-1*H*-1,2,3-triazole-4-carboxylate 35. The Boc was removed as described for **34**, the residue was dissolved in dry DMF (1 mL), and the solution cooled to 0 °C. Pyridine (0.5 mL) was added followed by DMAP (20 mg) and benzoyl chloride (140 mg, 1 mmol). The solution stirred at rt for 12 h. The same workup of **34** gave product **35** (91 mg, 76%). An analytical sample was crystallized from *i*-PrOH: mp 164−167 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49−6.92 (m, 15H), 3.87 (s, 3H); ^{13}C NMR (101 MHz $CDCl_3$) δ 164.3, 157.5, 147.3, 136.6, 135.9, 129.5, 129.0, 128.5 (2C), 128.4 (2C), 128.0 (3C), 127.8 (2C), 127.5 (2C), 127.2 (2C), 122.0 (2C), 51.9; ESI/MS (M + Na) 421. Anal. Calcd for $C_{23}H_{18}N_4O_3$ C, 69.34; H, 4.55; N, 14.06; O, 12.05. Found: C, 69.30; H, 4.57; N, 14.02.

Methyl 5-[[*N*-(*tert*-Butoxycarbonyl)-L-alanyl](phenyl)amino]-1-benzyl-1*H*-1,2,3-triazole-4-carboxylate 36, General Procedure. Compound **14** (48 mg, 0.1 mmol) was deprotected from Boc as previously described. The residue was dissolved in dry DMF (1 mL), and this solution was added to a solution containing *N*-Boc-AlaOH (96 mg, 0.5 mmol), DIPEA (0.39 mL, 2.5 mmol), and DMAP (5 mg) in dry DMF (1 mL) cooled to 0 °C. The mixture was gently warmed to 50 °C (water bath) and stirred at this temperature for 12. Then $CHCl_3$ (10 mL) was added, and the organic phase was washed with a solution of HCl 1 M (2 × 4 mL), $NaHCO_3$ 1 M (2 × 25 mL), water (2 mL), and brine (15 mL). The organic phase was separated and dried over anhydrous Na_2SO_4, and the solvent evaporated. Column chromatography (petroleum ether 40−60/EtOAc from 40:60 to 0:100) gave compound **36** (103 mg, 43%) as a waxy material: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51- 6.52 (m, 11H), 4.75 (d, J = 14.3 Hz, 1H), 4.48 (d, J = 14.3 Hz, 1H), 3.89 (s, 3H), 3.78−3.61 (m, 1H), 1.38−1.16 (m, 12H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.4, 160.37, 152.7, 139.0, 134.4, 134.2, 129.4, 129.1, 128.9, 128.3 (2C), 128.0 (2C), 127.7, 127.3, 125.9, 124.3, 123.6, 82.3, 52.4, 51.7, 27.5 (3), 19.1; HRMS (ESI) m/z calcd for $C_{25}H_{29}N_5O_5Na^+$ 502.2067, found 502.2063.

Methyl *N*-([1-Benzyl-5-[[*N*-(*tert*-butoxycarbonyl)-L-alanyl](phenyl)amino]-1*H*-1,2,3-triazol-4-yl]carbonyl)-L-alaninate 37. Starting from **33** and following the same procedure described for **36**, column chromatography (petroleum ether 40−60/EtOAc 40:60 to EtOAc/MeOH 98:2) gave compound **37** (20 mg, 36%) as a waxy material: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16−6.86 (m, 12H), 5.66−5.45 (m, 2H), 4.73 (d, J = 7.8 Hz, 1H), 4.66−4.55 (m, 1H), 3.88−3.53 (s, 3H), 1.49−1.31 (m, 12H), 1.23 (d, J = 6.0 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.5, 168.1, 152.7, 151.0, 140.3, 138.20, 138.1, 136.0, 134.3, 126.3 (2C), 125.9 (2C), 125.6 (2C), 125.2, 124.8, 121.3, 82.5, 55.8, 54.4, 53.1, 51.3, 27.8, 26.6 (3C), 18.5; HRMS (ESI) m/z calcd for $C_{28}H_{34}N_6O_6Na^+$ 573.2438, found 573.2434.

Dipeptide 38, General Procedure. Compound **20** (46 mg, 0.1 mmol) was dissolved in DMF (1 mL) followed by H-Ala(O-*t*-Bu) (73 mg, 0.5 mmol) and NMM (100 mg, 1 mmol). To this solution was added DMTMM-Cl (138 mg, 0.5 mmol) and the mixture stirred at rt for 6 h. Then $CHCl_3$ (5 mL) was added and the organic phase washed with a solution of HCl 1 M, (2 × 2 mL), $NaHCO_3$ 1 M (4 × 2 mL), water (2 mL) and brine (2 mL). The organic phase was separated and dried over anhydrous Na_2SO_4 and the solvent evaporated. Column chromatography (petroleum ether 40−60/EtOAc 40:60 to EtOAc/MeOH 98:2) gave compound **38** (42 mg, 71%) as a waxy material: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55−7.13 (m, 10H), 6.67−6.52 (m, 1H), 5.10 (d, J = 7.8 Hz, 1H), 4.40 (d, J = 6.9 Hz, 1H), 3.95 (s, 4H), 3.80−3.62 (m, 1H), 1.59−1.32 (m, 18H), 1.31 (d, J = 6.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.3, 164.9, 159.1, 152.8, 150.5, 139.4, 138.8, 129.3, 128.9, 128.5, 127.9, 127.8, 122.0, 80.2, 78.8, 65.0, 55.9, 52.0, 51.1, 32.1, 25.4, 25.4, 25.3, 25.1 (3C), 25.0 (3C), 25.05, 18.94; HRMS (ESI) m/z calcd for $C_{31}H_{39}N_5O_7Na^+$ 616.2748, found 616.2744.

Dipetide 39. Column chromatography (petroleum ether 40−60/EtOAc 40:60 to EtOAc/MeOH 98:2) gave compound **39** (41 mg, 74%) as a waxy material: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (s, 1H), 7.87−7.57 (m, 2H), 7.53−7.03 (m, 7H), 6.61 (t, J = 7.1 Hz, 1H), 5.23−4.98 (m, 1H), 4.08−3.78 (m, 4H), 3.79−3.57 (m, 4H), 3.57−3.42 (m, 1H), 1.72 (s, 9H), 1.29 (d, J = 6.5 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.2, 164.0, 160.4, 160.3, 160.0, 151.7, 151.7, 138.8, 138.7, 128.2 (2C), 128.1 (2C), 126.7 (2C), 126.6 (2C), 124.7, 82.7, 54.9, 51.0, 42.8, 37.9, 36.6, 27.5 (3C), 20.2; HRMS (ESI) m/z calcd for $C_{28}H_{33}N_5O_7Na^+$ 574.2278, found 574.2280.

Peptide 40. Compound **38** (40 mg, 0.072 mmol) was dissolved in MeOH (0.5 mL) and the solution added to 0.5 mL of a 1 M solution of NaOH at rt. The solution was stirred for 2 h and then cooled to 0 °C, and 0.6 mL of a 0.1 M solution of HCl was added. EtOAc (5 mL) was added and the organic phase rapidly separated and dried over anhydrous Na_2SO_4. The solvent was evaporated, the residue taken in dry toluene (5 mL), and the solvent evaporated under reduced pressure in order to dry the product. Oxalyl chloride (1 mL) was added and the solution stirred at rt for 3 h. The liquid phase was removed under vacuum (10 mmHg) and the residue dissolved in dry DMF (0.5 mL). This solution was added to a solution containing H-AlaOMe (20 mg, 0.2 mmol), EDC (77 mg, 0.5 mmol), DIPEA (0.2 mL, 1.3 mmol), and DMAP (5 mg) in dry CH_2Cl_2 (1 mL). The solution was stirred at rt for 6 h, then CH_2Cl_2 (10 mL) was added, and the organic phase was washed with a 10 aqueous solution of citric acid (2 × 4 mL), $NaHCO_3$ 1 M (2 × 25 mL), water (2 mL), and brine (15 mL). The organic phase was separated and dried over anhydrous Na_2SO_4 and the solvent evaporated. A solution prepared by dissolving Me_3SiCl (0.127 mL, 1 mmol) in dry MeOH (0.5 mL) was added and the mixture stirred at rt for 2 h. The solvent was evaporated and the residue dissolved in MeOH and passed through a LC-SCX cartridge for weak acids. First elution was done with MeOH, then H_2O and NH_4OH 2% in MeOH. The product was removed with 2% formic acid in MeOH. The solvent was evaporated to give compound **40** (20 mg, 56%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 11.06 (bs, 1H), 9.02−8.66 (m, 3H), 8.05−7.85 (m, 2H), 7.54−7.01 (m, 7H), 6.74−6.46 (m, 1H), 5.15−4.94 (m, 1H), 4.86−4.62 (m, 1H), 4.53 (m, 1H), 4.13−3.89 (m, 1H), 3.90−3.67 (m, 4H), 1.55−1.22 (m, 6H); ^{13}C NMR (101 MHz, $CDCl_3$*d*) δ 170.2, 168.1, 164.8, 160.3, 139.3, 137.6, 136.1, 130.3 (2C), 129.2 (2C), 128.6, 127.0 (2C), 124.9 (2C), 124.9, 119.9, 64.1, 54.5, 53.8, 51.9, 36.8, 22.7, 21.9; HRMS (ESI) m/z calcd for $C_{25}H_{28}N_6O_6Na^+$ 531.1968, found 531.1962.

Methyl *p*-[(Methoxyphenyl)methyl](*p*-anisoyl)-aminopropiolate 42. Amide **44** (1.03 g, 3.8 mmol) was dissolved in toluene (8 mL), and to this solution were added CuI (0.224 g, 1.17 mol), 1,10-phenanthroline (0.252 g, 1.4 mmol), and KHMDS (10 mL of a 0.5 M solution in toluene, 5 mmol) under nitrogen. After 30 min of stirring at rt, silane **7** (1.04 g, 4 mmol) was added and the flask sealed and heated at 90 °C for 6 h under stirring. After cooling, the solid was filtered away and the toluene evaporated and substituted with dry THF (10 mL). The solution was cooled to 0 °C, TBAF (0.954 g, 3.02 mmol) was added, and the solution was stirred at this temperature for 4 h. The solution was diluted with EtOAc (25 mL) and washed with a saturated solution of NH_4Cl and water. The organic layer was separated and dried over Na_2SO_4 and the solvent evaporated. A passage on a short column of silica gel gave the desilylated product practically pure for the next step (MS/ESI 296 $[M + 1]^+$). This product (0.950 g) was dissolved in dry THF (20 mL) and cooled to −78 °C. LHMDS (5.58 mL of a 1 M solution in THF, 5.58 mmol) was slowly added and the mixture stirred for 30 min at −78 °C and 1 h at −40 °C. At this temperature, methyl chloroformiate (0.404 g, 4.28 mmol) in dry THF (4 mL) was slowly added and the solution gently warmed to rt and stirred for 2 h. Standard aqueous workup followed by flash chromatography on silica gel (petroleum ether 40−60/EtOAc from 100:0 to 90:10) gave compound **42** (0.788 g, 46%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (d, J = 8.1 Hz, 2H), 7.10 (d, J = 7.1 Hz, 2H), 6.94 (d, J = 6.7 Hz, 2H), 6.79 (d, J = 7.3 Hz, 2H), 4.81 (s, 2H), 3.95 (s, 3H), 3.74 (d, J = 30.9 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.6, 161.6, 159.0, 130.6, 130.0, 127.9, 125.4, 113.4, 112.5, 99.1, 71.3, 54.9, 54.8, 52.2; ES/MS 376 $[M + Na]^+$. Anal. Calcd for $C_{20}H_{19}NO_5$ C, 67.98; H, 5.42; N, 3.96. Found: C, 67.99; H, 5.39; N, 3.98.

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Triazole Amide 45. To aryl azide **43** (186 mg, 0.5 mmol) dissolved in dry DMF (2.5 mL) at rt was added compound **42** (160 mg, 0.45 mmol). The flask was subjected to three vacuum−nitrogen cycles, then $(Cp^*RuCl)_4$ (24 mg, 0.022 mmol) was added followed by three other vacuum−nitrogen cycles. The reaction was stirred at room temperature until completion (monitored by TLC, 2 h). EtOAc and water were then added. The organic phase was extracted four times with EtOAc, washed with water (three times) and brine (one time), and dried over Na_2SO_4; the solvent was removed, and the mixture was purified by passage on a shorth path of silica. The crude was dissolved in $EtNH_2$ (2.0 mL of a solution 2 M in MeOH), and the mixture was heated for 24 h at 80 °C in a sealed tube. The solvent and the excess of amine were removed under reduced pressure, and the residue was submitted to column chromatography (petroleum ether 40−60/EtOAc 60:40). Compound **45** was obtained as a purple oil with a tendency to solidify on standing (175 mg, 55%). An analytical sample was obtained by crystallization from MeOH/water: mp 96−98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.92 (dd, J = 20.7, 5.1 Hz, 1H), 8.44−8.17 (m, 2H), 7.51 (dd, J = 21.6, 7.3 Hz, 7H), 7.40−7.05 (m, 10H), 7.01 (d, J = 8.4 Hz, 2H), 6.86 (d, J = 8.7 Hz, 2H), 6.29 (s, 1H), 5.53 (s, 2H), 5.15−4.91 (m, 4H), 3.93 (s, 3H), 3.78 (s, 3H), 3.51 (q, J = 7.2 Hz, 2H), 3.35 (d, J = 6.9 Hz, 1H), 1.32−1.01 (m, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.4, 160.0, 138.7, 138.2, 133.9, 133.0, 128.8, 128.4, 128.1, 127.2, 126.2, 124.4, 82.7, 65.7, 61.5, 58.7, 51.7, 51.4, 34.5, 27.2; MS-ESI 764 $[M + MeOH + Na]^+$. Anal. Calcd for $C_{43}H_{43}N_5O_5$: C, 72.76; H, 6.11; N, 9.87. Found: C, 72.79; H, 6.09; N, 9.86.

Amidotriazolylamide 41. Compound **45** (150 mg, 0.211 mmol) was dissolved in EtOH (5 mL), and $Pd(OH)_2/C$ (10 mg of a 10% dispersion on C, 0.01 mmol) was added. The mixture was stirred under an atmosphere of hydrogen (balloon) for 5 h while the reaction progress was monitored by TLC. The catalyst was filtered off through Celite, and the ethanol was removed under reduced pressure. The residue was dissolved in a mixture of DCM/water 3/1 (2 mL), DDQ (95 mg, 0.42 mmol) was added, and the mixture was stirred for 3 h at rt. The solvent was evaporated and the residue submitted to flash chromatography (DCM/MeOH, 90/10) to give **41** as a waxy material (24 mg, 26% yield): ^{1}H NMR (400 MHz, CD_3OD) δ 7.80 (d, J = 8.8 Hz, 2H), 7.10 (s, 1H), 6.95 (d, J = 8.8 Hz, 2H), 6.46 (s, 1H), 3.82 (s, 3H), 3.40 (d, J = 7.3 Hz, 2H), 3.24−3.06 (m, 1H), 1.21 (t, J = 7.2 Hz, 3H), 1.13 (d, J = 6.8 Hz, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 162.9, 156.7, 152.2, 149.8, 145.2, 133.8, 129.2, 126.6, 125.9, 124.5, 124.2, 113.8, 113.1, 102.1, 54.2, 33.2, 25.7, 21.2, 13.2; HRMS (ESI) m/z calcd for $C_{22}H_{25}N_5O_5Na^+$ 462.1754, found 462.1751.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

General description of modeling studies, HPLC conditions for control of stereochemical integrity of compounds **20**, **21**, **32**, **33**, and **36**, ORTEP diagram of **39**, and spectra of compounds **10**−**21**, **25**−**42**, and **45**. This material is available free of charge via the Internet at http://pubs.acs.org."

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Notes

The authors declare no competing financial interest.

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