Synthesis of Self-Folded Molecular Rotors Controlled by Edge-to-Face CH/π Aromatic Interactions

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Abstract: A series of novel self-folded molecular rotors were synthesized and characterized by ^{1}H NMR, ^{13}C NMR, HRMS, and IR data. All but two compounds were also studied by X-ray crystallography.

Key words: self-folded, molecular rotors, CH/π interactions, molecular clips, diethoxycarbonyl glycoluril

Edge-to-face orientations between aromatic rings were initially observed almost 50 years ago in the herringbone structure of crystalline benzene.[1] However, the significance of these relatively weak edge-to-face CH/π aromatic interactions did not become evident until 1985 when Burley and Petsko, and Singh and Thornton presented evidence that they played a significant role in protein structure.[2] Edge-to-face aromatic interactions can also be important in such diverse areas as crystal packing and crystal engineering,[3,4] supramolecular assemblies and host-guest binding,[5] drug–receptor interactions,[6] and other areas of molecular recognition.[7] Examples have emerged where intramolecular edge-to-face interactions have a considerable role in determining the conformation of flexible organic molecules in solution and in the crystalline state.[8]

In addition, facing the challenge of constructing nanoscale machines, it has been noted that molecular motors stand out as essential components to provide power to such systems.[9] The diversity of fascinating biological motors, such as the kinesin or myosin linear and ATP-ase rotary motor systems,[10] has been a source of inspiration for the development of artificial molecular mechanical devices (such as switches, shuttles, and muscles)[11] and a variety of elegant rotor systems.[12] A number of systems have been designed in which movement or change in shape occurs in response to external chemical, electrochemical, or photochemical stimuli.[13] Until now, few rotor systems that are controlled by CH/π aromatic interactions have been reported. Following our previous work,[14] herein we report the synthesis of self-folded molecular rotors controlled by edge-to-face CH/π aromatic interactions.

The synthetic route used to obtain clip molecules **7a–l** is shown in Scheme 1. Compounds **4** and **5a–g** were synthesized as reported previously.[15] Intermediates **5h** and **5i** were produced from **5g** through Sonogashira cross-coupling reactions (see Supporting Information). The reaction of intermediates **5a–i** with commercial aliphatic amines **6a–d** in DMF, in the presence of formaldehyde, resulted in the formation of clip molecules **7a–l** (Table 1). Much to our satisfaction, the experimental results showed that most substrates afforded the expected products in good yields. The series inspired us to research the influence of the substituents of flexible side walls (R^5–R^9) and rigid side walls (R^1–R^4) on the edge-to-face aromatic interaction.

All compounds **7a–l** gave satisfying ^{1}H NMR, ^{13}C NMR, HRMS, and IR data. For all but compounds **7h** and **7i**, crystals of appropriate size and quality for single crystal X-ray diffraction studies were obtained. It was found that all compounds adopted a conformation in which the flexible side walls and the rigid side walls were almost orthogonal, and the crystal structures contained weak CH/π interactions of the edge-to-face type (Figure 1). Such CH/π interaction is known to arise from hydrogen bonding between soft acids and soft bases. Modifying the electronic properties of the aromatic substituents allows the strength of such interactions to be varied. However, according to the ^{1}H NMR spectra of these compounds (see Supporting Information), the peaks attributed to H-1 and H-2 appeared at the same position (Figure 1). It could therefore be concluded that the C–C bond adjacent to the aromatic ring could freely rotate in solution state but was fixed by intramolecular CH/π interaction in the solid state.

As shown for compounds **7a–d** in Figure 2, substitution of the hydrogen atoms in the π-aromatic ring by electron-donating groups [**7b** (CH_3) and **7c** (OCH_3)] or an electron-withdrawing group [**7d** (Br)] was accompanied, respec-

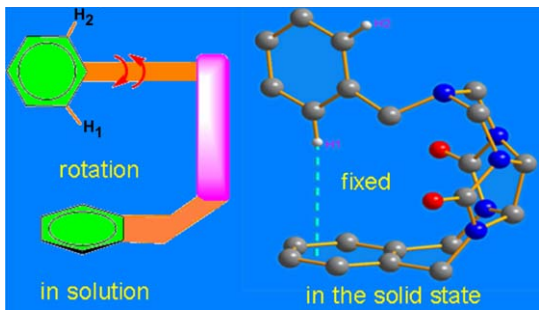

Figure 1 Fast rotation in solution and fixed conformation in solid state of clip molecules

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tively, by an increase or decrease in the degree of the conformational folding. The distance between the aromatic CH and the best plane of the phenyl ring was found to be shorter in **7b** (2.835 Å) and **7c** (2.905 Å) than in the non-substituted analogue **7a** (3.077 Å), and longer in **7d** (3.260 Å) than in **7a**.

Table 1 Isolated Yields and Products in the Synthesis of Clip Molecules from Various Substrates

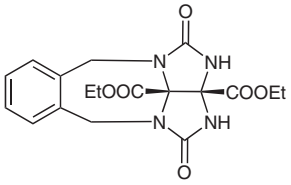
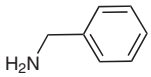
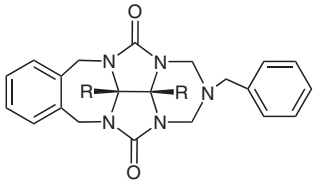
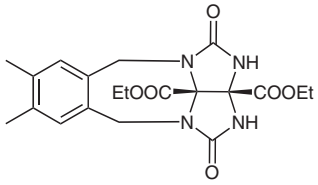
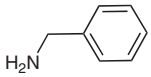
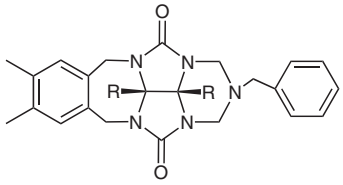
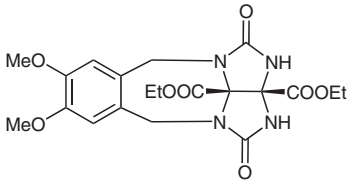
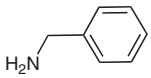
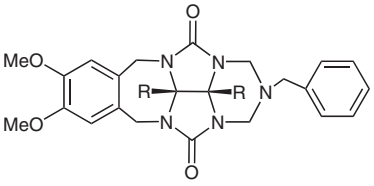
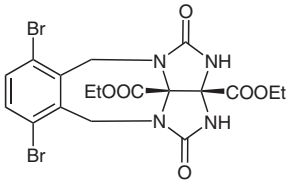
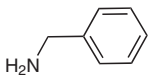
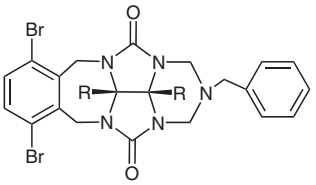
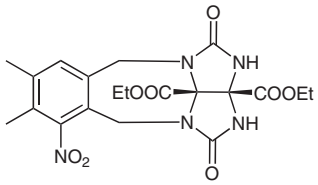
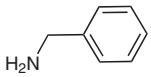
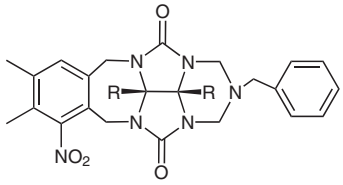
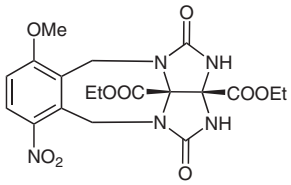
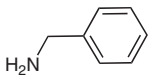
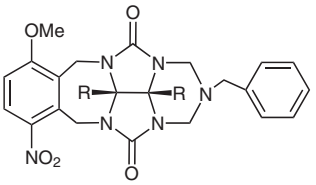
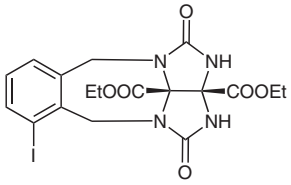
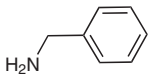
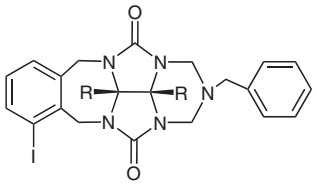
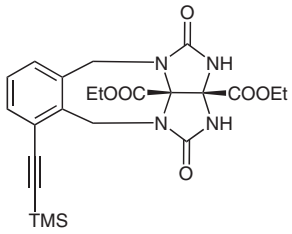
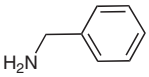
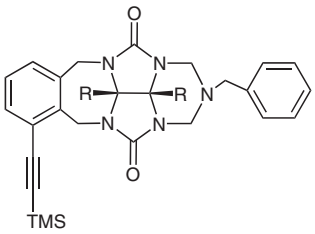
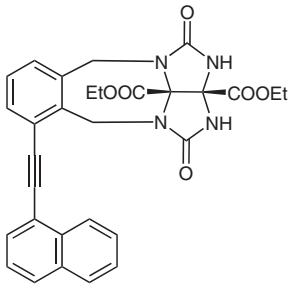
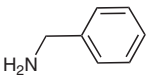
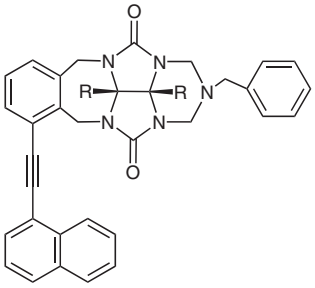
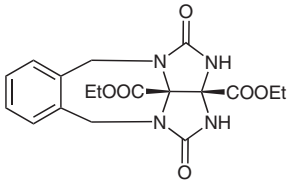
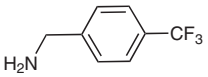
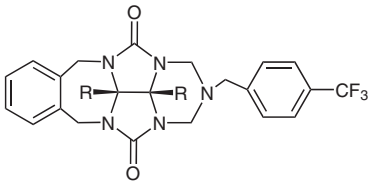
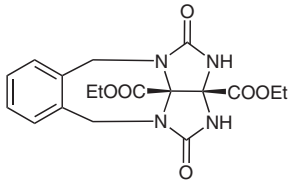
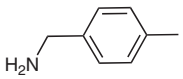
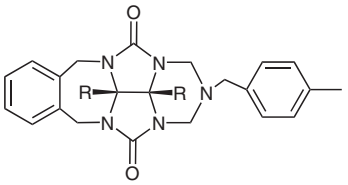
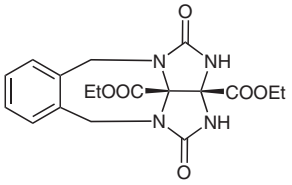
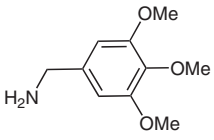
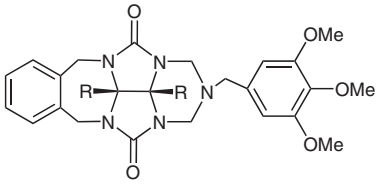
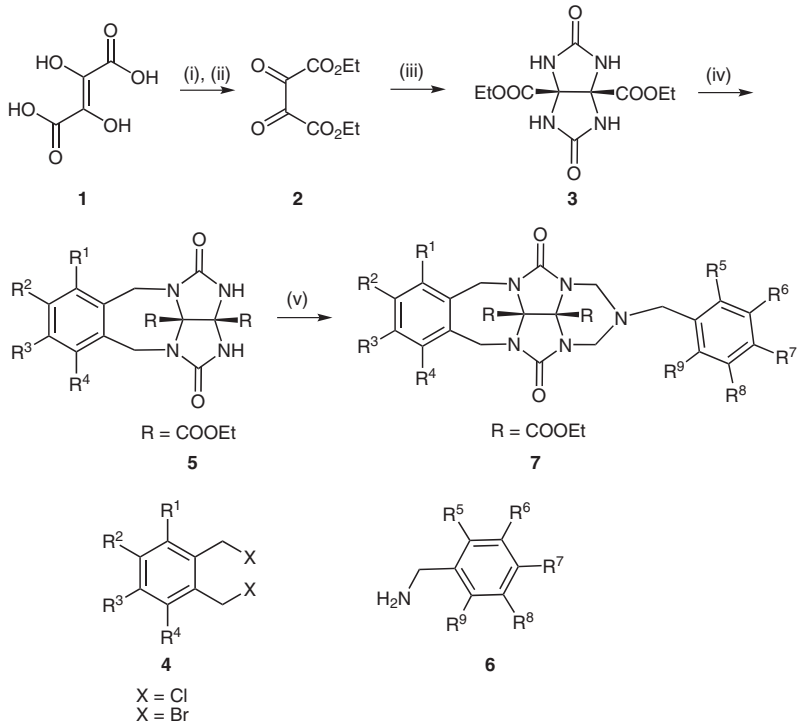
Entry	**5a–j**	**6a–d**	Product (R = COOEt)	Yield (%)[a]
1	 **5a**	 **6a**	 **7a**	58
2	 **5b**	 **6a**	 **7b**	45
3	 **5c**	 **6a**	 **7c**	67
4	 **5d**	 **6a**	 **7d**	45
5	 **5e**	 **6a**	 **7e**	50
6	 **5f**	 **6a**	 **7f**	52
7	 **5g**	 **6a**	 **7g**	56

Table 1 Isolated Yields and Products in the Synthesis of Clip Molecules from Various Substrates (continued)

Entry	5a–j	6a–d	Product (R = COOEt)	Yield (%)[a]
8	 5h	 **6a**	 **7h**	82
9	 **5i**	 **6a**	 **7i**	58
10	 **5a**	 **6b**	 **7j**	25
11	 **5a**	 **6c**	 **7k**	65
12	 **5a**	 **6d**	 **7l**	72

[a] Isolated yield of last step.

This finding was consistent with the expectation that increasing the π-electron density of the aromatic ring will favor the CH/π-interacting conformation.[16] For **7e**, the incorporation of an *ortho*-nitro group into molecule **7b** was found to be unfavorable to the CH/π systems. In this case, the CH/π distance now became 2.895 Å, so the strength of the interaction was much weaker than that of **7b**. When introducing an *ortho*-nitro and an *ortho*-methoxy to **7a** simultaneously, the π-system of **7f** was found to be more electron-deficient than that of **7a** as a longer distance between the CH and the π-ring was noted (3.144 Å). The distance in **7g** was similar to that found in **7a** (2.949 Å), which may be due to the weak electron-withdrawing effect of the iodine atom. For compounds **7j**, **7k** and **7l**, electron-donating groups [**7k** (CH_3) and **7l** (OCH_3)] or an electron-withdrawing group [**7j** (CF_3)] were incorporated into the CH aromatic ring, respectively. It was found that a stronger electron-donating effect resulted in weaker CH/π interactions, which is in agreement with the hydrogen bond nature of the CH/π interaction. Surprisingly, the CH/π hydrogen bond in **7j** was a little weaker than that found in **7a**, according to the distance between the CH and the π-ring (3.157 Å). This may be due to the special chemical properties of the fluorine atom.



Scheme 1 *Reagents and conditions*: (i) AcOH, Br_2, H_2O; (ii) EtOH, HCl (g), 0 °C; (iii) PhH, H_2NCONH_2, TFA, reflux; (iv) **4**, *t*-BuOK, DMSO; (v) **6**, HCHO (37%), DMF.

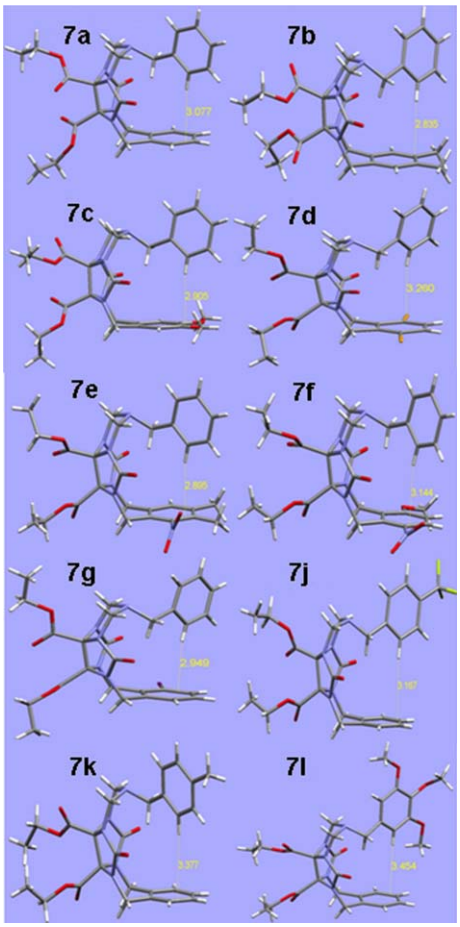


Figure 2 Substituent effects on CH/π interactions in the solid state

In summary, we reported the synthesis of a series of novel self-folded molecular rotors in which the conformation was controlled by the intramolecular CH/π interaction.[17,18] In addition, the ^{1}H NMR spectra and the crystal structure analysis provide strong evidence for the substituent effects on CH/π interaction. The exact mechanism and the development of a controllable molecular rotor are under investigation.

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synlett.

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(17) **Synthesis of 7; General Procedure**
DMF and the aliphatic amines had to be freshly distilled or recrystallized under nitrogen. Compounds **4** and **5a**–**g** were synthesized as reported previously.[15] The intermediates **5h** and **5i** were then produced from **5g** through Sonogashira cross-coupling reactions. Thus, a suspension of **5** (5 mmol) in 37% aq formaldehyde (3.5 mL) and DMF (30 mL) was brought to reflux under magnetic stirring. A solution of aliphatic amine (5 mmol) in DMF (20 mL) was added slowly, dropwise (over 1 h) to the mixture. Refluxing was continued and the reaction was monitored by TLC. Upon completion, the solvent was removed under reduced pressure and the products were separated by column chromatography on silica gel ($CHCl_3$–MeOH) to give compound **7** as a solid.
(18) Compound **7a**: Yield: 58%; white solid; mp 159–160 °C; IR (KBr): 2960, 2923, 2852, 1737, 1635, 1377, 1267, 752, 722 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.50–7.47 (m, 2 H), 7.30–7.19 (m, 5 H), 6.88–6.85 (m, 2 H), 4.86 (d, *J* = 15.6 Hz, 2 H), 4.65 (d, *J* = 15.2 Hz, 4 H), 4.39–4.25 (m, 6 H), 2.88 (s, 2 H), 1.38–1.25 (m, 6 H); ^{13}C NMR ($CDCl_3$,100 MHz): δ = 165.9, 165.6, 156.9, 136.2, 130.0, 129.0, 128.0, 127.4, 114.2, 80.3, 75.9, 63.3, 63.2, 59.8, 53.7, 45.5, 14.0, 13.9; HRMS: *m/z* $[M + H]^+$ calcd for $C_{27}H_{29}N_5O_6$: 519.2118; found: 520.2191.
Compound **7b**: Yield: 45%; white solid; mp 160–161 °C; IR (KBr): 3064, 2973, 2938, 1738, 1718, 1452, 1414, 1263, 752 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.24–7.18 (m, 5 H), 6.85–6.82 (m, 2 H), 4.77 (d, *J* = 15.6 Hz, 2 H), 4.62 (d, *J* = 13.6 Hz, 2 H), 4.57 (d, *J* = 15.6 Hz, 2 H), 4.37–4.24 (m, 6 H), 2.87 (s, 2 H), 2.22 (s, 6 H), 1.36–1.28 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.9, 165.7, 156.9, 136.5, 136.0, 133.4, 131.2, 128.9, 127.9, 127.2, 80.4, 75.9, 63.1, 63.0, 59.8, 53.7, 45.0, 19.1, 13.9, 13.8; HRMS: *m/z* $[M + H]^+$ calcd for $C_{29}H_{33}N_5O_6$: 547.2431; found: 548.2504.
Compound **7c**: Yield: 67%; white solid; mp 228–229 °C; IR (KBr): 3069, 2957, 2936, 2852, 1762, 1718, 1465, 1417, 1282, 741 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.21–7.19 (m, 3 H), 7.00–6.91 (m, 4 H), 4.78 (d, *J* = 16.0 Hz, 2 H), 4.68 (d, *J* = 14.0 Hz, 2 H), 4.61 (d, *J* = 16.0 Hz, 2 H), 4.40–4.28 (m, 6 H), 3.91 (s, 6 H), 2.94 (s, 2 H), 1.38–1.30 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.9, 165.7, 156.9, 147.7, 136.3, 128.9, 128.7, 127.9, 127.2, 113.3, 80.3, 76.0, 63.2, 63.1, 59.8, 56.0, 53.6, 45.1, 13.9, 13.8; HRMS: *m/z* $[M + H]^+$ calcd for $C_{29}H_{33}N_5O_8$: 579.2329; found: 580.2402.
Compound **7d**: Yield: 45%; yellow solid; mp 247–248 °C; IR (KBr): 3061, 2927, 2852, 1761, 1743, 1721, 1457, 1420, 1251, 752 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.42–7.21 (m, 5 H), 6.95 (d, *J* = 6.8 Hz, 2 H), 5.67 (d, *J* = 16.0 Hz, 2 H), 4.68 (d, *J* = 13.6 Hz, 2 H), 4.57 (d, *J* = 16.0 Hz, 2 H), 4.40–4.26 (m, 6 H), 3.00 (s, 2 H), 1.38–1.30 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.7, 165.5, 156.7, 137.8, 136.2, 133.9, 129.1, 128.1, 127.4, 124.2, 79.0, 76.4, 63.4, 63.2, 59.9, 54.0, 44.9, 14.0, 13.9; HRMS: *m/z* $[M + H]^+$ calcd for $C_{27}H_{27}Br_2N_5O_6$: 675.0328; found: 676.0401. Compound **7e**: Yield: 50%; white solid; mp 163–165 °C; IR (KBr): 3448, 2984, 1772, 1619, 1533, 1459, 1420, 1368, 1319, 1259, 1224, 1154, 1099, 1077, 1027, 980, 914, 852, 815 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.44 (s, 1 H), 7.29–7.23 (m, 3 H), 6.93–6.92 (d, *J* = 6.8 Hz, 2 H), 4.93 (d, *J* = 16.0 Hz, 1 H), 4.87 (d, *J* = 16.0 Hz, 1 H), 4.85–4.53 (m, 4 H), 4.37–4.25 (m, 6 H), 2.90 (s, 2 H), 2.33 (s, 3 H), 2.20 (s, 3 H), 1.37–1.29 (m, 6 H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ = 165.6, 165.4, 156.9, 156.4, 152.1, 138.5, 136.3, 135.0, 133.2, 129.1, 128.1, 127.4, 126.3, 79.7, 76.0, 63.4, 63.2, 59.9, 59.8, 53.9, 45.2, 39.7, 19.9, 14.5, 13.9, 13.8; HRMS: *m/z* $[M + H]^+$ calcd for $C_{29}H_{32}N_6O_8$: 592.2282; found: 593.2354.
Compound **7f**: Yield: 52%; white solid; mp 158–160 °C; IR (KBr): 3062, 2977, 2937, 2847, 1754, 1718, 1520, 1470, 1423, 1276, 814, 744 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ = 7.86 (d, *J* = 9.2 Hz, 1 H), 7.28–7.22 (m, 3 H), 6.93–6.89

(m, 3 H), 5.80 (d, *J* = 16.8 Hz, 1 H), 5.74 (d, *J* = 16.0 Hz, 1 H), 4.68 (d, *J* = 14.0 Hz, 1 H), 4.62 (d, *J* = 16.8 Hz, 1 H), 4.52 (d, *J* = 14.4 Hz, 1 H), 4.40 (d, *J* = 14.0 Hz, 1 H), 4.38–4.21 (m, 6 H), 4.00 (s, 3 H), 2.99 (d, *J* = 13.2 Hz, 1 H), 2.66 (d, *J* = 13.6 Hz, 1 H), 1.38–1.25 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.7, 165.5, 160.3, 156.7, 144.2, 136.2, 133.5, 129.1, 128.1, 127.5, 126.9, 126.0, 110.6, 79.3, 63.4, 63.2, 60.6, 58.9, 56.8, 53.9, 38.6, 36.7, 13.9, 13.8; HRMS: *m/z* [M + H]$^+$ calcd for $C_{28}H_{30}N_6O_9$: 594.2074; found: 595.2147.

Compound **7g**: Yield: 56%; white solid; mp 233–234 °C; IR (KBr): 3448, 2979, 2935, 2825, 1950, 1754, 1721, 1585, 1558, 1497, 1465, 1417, 1372, 1301, 1277, 1252, 1213, 1168, 1141, 1110, 1073, 1029, 986, 961, 910, 862, 828 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.83 (d, *J* = 8.0 Hz, 1 H), 7.47 (d, *J* = 8.0 Hz, 1 H), 6.94–6.88 (m, 3 H), 5.45 (d, *J* = 16.0 Hz, 1 H), 4.88 (d, *J* = 16.0 Hz, 1 H), 4.68–4.39 (m, 4 H), 4.37–4.26 (m, 6 H), 2.94 (d, *J* = 14.0 Hz, 1 H), 2.88 (d, *J* = 14.0 Hz, 1 H), 1.38–1.30 (m, 6 H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ = 165.7, 165.5, 156.9, 156.7, 139.9, 139.4, 136.8, 136.3, 130.8, 129.3, 129.0, 128.0, 127.3, 100.6, 79.4, 76.2, 63.2, 63.1, 60.0, 59.6, 53.8, 49.7, 46.0, 13.4, 13.8; HRMS: *m/z* [M + H]$^+$ calcd for $C_{27}H_{28}IN_5O_6$: 645.1084; found: 646.1157.

Compound **7h**: Yield: 82%; white solid; mp 212–213 °C; IR (KBr): 3448, 3066, 2960, 2930, 2851, 2153, 1772, 1652, 1587, 1544, 1461, 1419, 1368, 1318, 1254, 1223, 1157, 1098, 1098, 1077, 1027, 987, 919, 905, 859 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.44 (d, *J* = 7.6 Hz, 2 H), 7.29–7.20 (m, 4 H), 6.93 (d, *J* = 7.6 Hz, 2 H), 5.73 (d, *J* = 16.0 Hz, 1 H), 4.84 (d, *J* = 16.0 Hz, 1 H), 4.70 (d, *J* = 14.4 Hz, 1 H), 4.62 (d, *J* = 14.4 Hz, 1 H), 4.60 (d, *J* = 16.4 Hz, 1 H), 4.49 (d, *J* = 16.4 Hz, 1 H), 4.38–4.25 (m, 6 H), 3.02 (d, *J* = 13.2 Hz, 1 H), 2.87 (d, *J* = 13.2 Hz, 1 H), 1.38–1.26 (m, 6 H), 0.30 (s, 9 H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ = 166.1, 165.8, 157.1, 156.6, 138.5, 136.6, 132.4, 130.3, 129.2, 128.9, 128.2, 128.0, 127.5, 127.3, 123.9, 102.3, 99.6, 80.1, 76.1, 63.3, 63.1, 60.4, 59.5, 54.0, 45.7, 42.5, 14.0, 13.9; HRMS: *m/z* [M + H]$^+$ calcd for $C_{32}H_{37}N_5O_6Si$: 615.2513; found: 616.2586.

Compound **7i**: Yield: 58%; white solid; mp 288–289 °C; IR (KBr): 3424, 3059, 2983, 2930, 2846, 1739, 1721, 1588, 1545, 1460, 1420, 1368, 1315, 1259, 1224, 1172, 1148, 1080, 1026, 984, 917, 905, 854, 802 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.63 (d, *J* = 8.4 Hz, 1 H), 7.90–7.84 (m, 2 H), 7.65–7.45 (m, 5 H), 7.33–7.29 (m, 2 H), 7.25–6.97 (m, 3 H), 6.95–5.90 (m, 2 H), 5.95 (d, *J* = 16.0 Hz, 1 H), 4.90 (d, *J* = 16.0 Hz, 1 H), 4.75–4.63 (m, 4 H), 4.57–4.26 (m, 6 H), 3.06 (d, *J* = 13.6 Hz, 1 H), 2.97 (d, *J* = 13.6 Hz, 1 H), 1.38–1.25 (m, 6 H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ = 165.9, 165.6, 156.9, 156.6, 137.8, 136.8, 133.3, 133.1, 132.3, 130.9, 130.3, 129.3, 128.9, 127.8, 127.5, 126.9, 126.5, 126.4, 125.3, 124.2, 120.7, 92.3, 91.6, 80.1, 75.9, 63.4, 63.3, 59.4, 53.9, 45.7, 42.8, 13.9 cm^{-1}. HRMS: *m/z* [M + H]$^+$ calcd for $C_{39}H_{35}N_5O_6$: 669.2587; found: 670.2660.

Compound **7j**: Yield: 25%; white solid; mp 177–179 °C; IR (KBr): 3066, 2956, 2922, 1737, 1716, 1460, 1416, 1266, 850, 750 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.51–7.45 (m, 4 H), 7.32–7.29 (m, 2 H), 6.94 (d, *J* = 2.0 Hz, 2 H), 4.86 (d, *J* = 15.6 Hz, 2 H), 4.64 (d, *J* = 15.6 Hz, 2 H), 4.60 (d, *J* = 14.0 Hz, 2 H), 4.39–4.28 (m, 6 H), 2.90 (s, 2 H), 1.38–1.25 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.8, 165.6, 157.0, 140.5, 136.2, 130.0, 129.1, 128.0, 125.0, 122.8, 80.3, 75.9, 63.3, 59.9, 53.2, 45.5, 29.7, 14.0; HRMS: *m/z* [M + H]$^+$ calcd for $C_{28}H_{28}F_3N_5O_6$: 587.1992; found: 588.2064.

Compound **7k**: Yield: 65%; white solid; mp136–139 °C; IR (KBr): 3053, 2992, 2966, 2906, 1761, 1715, 1416, 1415, 1254, 820, 739 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.49–7.46 (m, 2 H), 7.29–7.26 (m, 2 H), 7.01 (d, *J* = 7.6 Hz, 2 H), 6.75 (d, *J* = 8.0 Hz, 2 H), 4.86 (d, *J* = 16.0 Hz, 2 H), 4.64 (d, *J* = 16.0 Hz, 2 H), 4.37–4.27 (m, 6 H), 2.84 (s, 2 H), 2.27 (s, 3 H), 1.38–1.30 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 166.0, 165.7, 156.9, 136.8, 136.2, 133.4, 130.0, 128.9, 128.7, 128.0, 80.3, 76.0, 63.2, 63.1, 59.8, 53.5, 45.4, 21.0, 14.0, 13.9; HRMS: *m/z* [M + H]$^+$ calcd for $C_{28}H_{31}N_5O_6$: 533.2274; found: 534.2347.

Compound **7l**: Yield: 72%; white solid; mp 190–192 °C; IR (KBr): 3068, 2981, 2954, 2841, 1766, 1738, 1719, 1466, 1421, 1226, 736 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.47–7.43 (m, 2 H), 7.27–7.24 (m, 2 H), 6.12 (s, 2 H), 4.86 (d, *J* = 16.0 Hz, 2 H), 4.65 (d, *J* = 15.6 Hz, 4 H), 4.38–4.29 (m, 6 H), 3.81 (s, 6 H), 3.79 (s, 3 H), 2.81 (s, 2 H), 1.38–1.31 (m, 6 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 165.8, 165.5, 156.9, 152.5, 136.6, 136.2, 131.8, 129.7, 127.8, 105.7, 80.2, 75.8, 63.2, 63.1, 60.6, 59.6, 55.8, 54.0, 45.3, 13.9, 13.8; HRMS: *m/z* [M + H]$^+$ calcd for $C_{30}H_{35}N_5O_9$: 609.2435; found: 610.2508.

(19) Crystal data for compound **7a**: $C_{27}H_{29}N_5O_6$; MW = 519.55; monoclinic; *a* = 15.655(4), *b* = 8.752(2), *c* = 19.427(5) Å, *β* = 110.550(5)°; *V* = 2492.4(11) Å^3; *T* = 292(2) K; space group $P2_1/n$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.100 mm^{-1}; 13703 reflections measured, 4889 unique (R_{int} = 0.0476) which were used in all calculations. The final *wR*2 (F_2) was 0.1980 (all data).

For compound **7b**: $C_{29}H_{33}N_5O_6$; MW = 547.60; monoclinic; *a* = 9.9597(9), *b* = 23.109(2), *c* = 12.4028(11) Å, *β* = 101.193(2)°; *V* = 2800.3(4) Å^3; *T* = 292(2) K; space group $P2_1/c$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.092 mm^{-1}; 14003 reflections measured, 4926 unique (R_{int} = 0.0343) which were used in all calculations. The final *wR*2 (F_2) was 0.1755 (all data).

For compound **7c**: $C_{29}H_{33}N_5O_8$; MW = 579.60; monoclinic; *a* = 8.1464(6), *b* = 23.9524(17), *c* = 15.0281(11) Å, *β* = 104.7310(10)°; *V* = 2836.0(4) Å^3; *T* = 292(2) K; space group $P2_1/n$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.100 mm^{-1}; 33110 reflections measured, 6772 unique (R_{int} = 0.0987) which were used in all calculations. The final *wR*2 (F_2) was 0.1729 (all data).

For compound **7d**: $C_{27}H_{27}Br_2N_5O_6$; MW = 677.36; triclinic; *a* = 9.136(3), *b* = 10.144(3), *c* = 15.028(4) Å, *α* = 90.784(5)°, *β* = 94.628(5)°, *γ* = 94.984(5)°; *V* = 1382.6(7) Å^3; *T* = 292(2) K; space group $P\bar{1}$, *Z* = 2; μ(Mo-K$_\alpha$) = 2.983 mm^{-1}; 13279 reflections measured, 5386 unique (R_{int} = 0.1158) which were used in all calculations. The final *wR*2 (F_2) was 0.1795 (all data).

For compound **7e**: $C_{29}H_{32}N_6O_8$; MW = 592.61; monoclinic; *a* = 7.9571(4), *b* = 15.6173(6), *c* = 22.8959(10) Å, *β* = 94.0820(10)°; *V* = 2838.0(2) Å^3; *T* = 292(2) K; space group $P2_1/c$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.103 mm^{-1}; 21931 reflections measured, 4992 unique (R_{int} = 0.0254) which were used in all calculations. The final *wR*2 (F_2) was 0.1761 (all data).

For compound **7f**: $C_{56}H_{64}N_{12}O_{19}$; MW = 1209.19; tetragonal; *a* = 15.9660(6), *b* = 15.9660(6), *c* = 11.1270(9) Å, *α* = *β* = *γ* = 90.00°; *V* = 2836.4(3) Å^3; *T* = 292(2) K; space group $P4_3$; *Z* = 2; μ(Mo-K$_\alpha$) = 0.108 mm^{-1}; 32120 reflections measured, 6183 unique (R_{int} = 0.1055) which were used in all calculations. The final *wR*2 (F_2) was 0.1147 (all data).

For compound **7g**: $C_{27}H_{28}IN_5O_6$; MW = 645.44; monoclinic; *a* = 9.0743(10), *b* = 25.339(3), *c* = 11.6956(13) Å, *β* = 90.212(2)°; *V* = 2689.2(5) Å^3; *T* = 292(2) K; space group $P2_1/c$; *Z* = 4; μ(Mo-K$_\alpha$) = 1.242 mm^{-1}; 30097

reflections measured, 5852 unique (R_{int} = 0.0924) which were used in all calculations. The final *wR*2 (F_2) was 0.1632 (all data).

For compound **7j**: $C_{28}H_{28}F_3N_5O_6$; MW = 587.55; triclinic; *a* = 9.2056(13), *b* = 12.8972(18), *c* = 13.3762(19) Å, *α* = 113.437(2)°, *β* = 98.874(2)°, *γ* = 99.525(2)°; *V* = 1393.8(3) Å^3; *T* = 292(2) K; space group $P\bar{1}$; *Z* = 2; μ(Mo-K$_\alpha$) = 0.113 mm^{-1}; 14646 reflections measured, 5445 unique (R_{int} = 0.0559) which were used in all calculations. The final *wR*2 (F_2) was 0.1554 (all data).

For compound **7k**: $C_{28}H_{31}N_5O_6$; MW = 533.58; orthorhombic; *a* = 18.049(4), *b* = 18.263(4), *c* = 8.0492(17) Å, *α* = *β* = *γ* = 90.00°; *V* = 2653.3(10) Å^3; *T* = 292(2) K; space group $Pna2_1$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.096 mm^{-1}; 26452 reflections measured, 3099 unique (R_{int} = 0.0885) which were used in all calculations. The final *wR*2 (F_2) was 0.1101 (all data).

For compound **7l**: $C_{30}H_{35}N_5O_9$; MW = 613.63; monoclinic; *a* = 8.9216(5), *b* = 29.5203(17), *c* = 11.5079(6) Å, *β* = 90.5000(10)°; *V* = 3030.7(3) Å^3; *T* = 292(2) K; space group $P2_1/n$; *Z* = 4; μ(Mo-K$_\alpha$) = 0.101 mm^{-1}; 23651 reflections measured, 5919 unique (R_{int} = 0.0768) which were used in all calculations. The final *wR*2 (F_2) was 0.2164 (all data).

CCDC-724320 (**7a**); CCDC-724321 (**7b**); CCDC-724322 (**7c**); CCDC-724323 (**7d**); CCDC-724324 (**7e**); CCDC-724325 (**7f**); CCDC-724326 (**7g**); CCDC-724327 (**7j**); CCDC-724328 (**7k**); CCDC-724329 (**7l**). These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44(1223)336033; email: deposit@ccdc.cam.ac.uk].