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Efficient Syntheses of C^8-Aryl Adducts of Adenine and Guanine Formed by Reaction of Radical Cation Metabolites of Carcinogenic Polycyclic Aromatic Hydrocarbons with DNA

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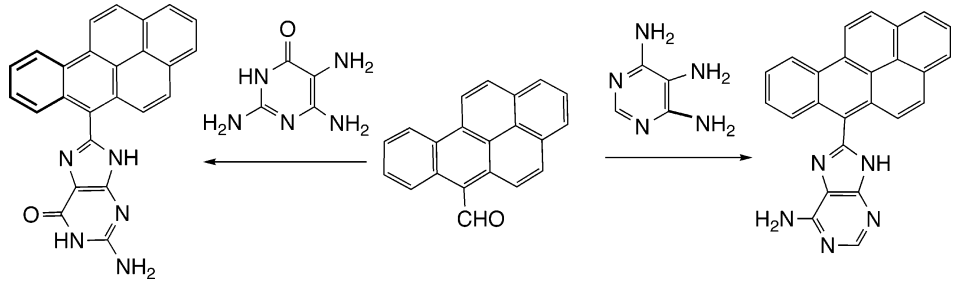

The synthesis of the C^8-aryl adducts of adenine and guanine formed by reaction of the radical cation metabolites of carcinogenic polycyclic aromatic hydrocarbons (PAHs), such as benzo[*a*]pyrene (BP) and dibenzo[*def*,*p*]chrysene (DBC), with DNA is reported. The synthetic approach involves in the key step direct reaction of a PAH aldehyde with a di- or triamine precursor of a purine. The method is operationally simple, affords good yields of adducts, and is broad in its scope. The C^8-aryl adducts of adenine and guanine derived from BP (6-BP-8-Ade and 6-BP-8-Gua) and DBC (10-DBC-8-Ade and 10-DBC-8-Gua) were synthesized in good yields by this method. Analogous C^8-aryl adenine and guanine derivatives of other PAHs (anthracene, benz[*a*]anthracene, and chrysene) were also readily prepared via this approach. This method of synthesis is superior to the only method that is currently available. It entails direct reaction of short-lived PAH radical cations (generated electrochemically or chemically) with 2′-deoxyribonucleosides or the corresponding purine bases. It provides the adducts in low yields accompanied by complex mixtures of secondary products. An alternative synthesis that involves Pd-catalyzed Suzuki−Miyaura coupling of arylboronic acids with 8-bromopurine nucleosides was also investigated. Although the C^8-purine adducts of PAHs, such as naphthalene, phenanthrene, pyrene, and chrysene, could be prepared by this method, analogous adducts of carcinogenic PAHs and other structurally related PAHs, e.g., anthracene, benz[*a*]anthracene, benzo[*a*]pyrene, and dibenzo[*def*,*p*]chrysene, could not be obtained. This difference was shown to be a consequence of the facility of competing hydrolytic deboronation of the corresponding arylboronic acids.

Introduction

Polycyclic aromatic hydrocarbons (PAHs), some of which are potent carcinogens, are ubiquitous environmental pollutants produced in the combustion of organic matter.[1] They are commonly present in smoke from combustion of fossil fuels, tobacco smoke, and smoked and fried foods. Benzo[*a*]pyrene (BP) is the most intensively investigated PAH carcinogen, and it has been implicated as a principal cancer-causative agent in cigarette smoke.[2−4]

* Address correspondence to this author. Phone: 1-(773) 702-6998. Fax: 1-(773) 702-6260.

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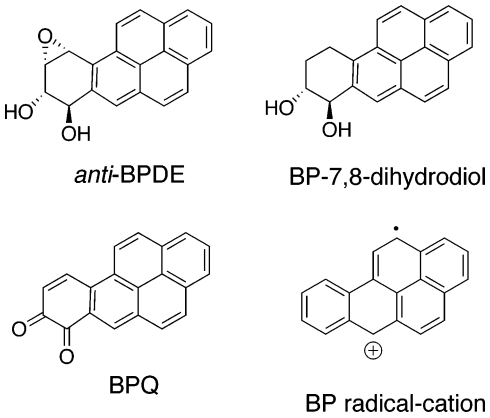

FIGURE 1. Active metabolites of benzo[*a*]pyrene.

BP and other PAHs are activated enzymatically to reactive forms that attack DNA resulting in formation of adducts that lead initially to mutations and ultimately to tumor induction.[5−7] Three principal routes of PAH activation have been postulated: (1) the diol-epoxide path [mediated by cytochrome P-450 (CYP) enzymes], (2) the *o*-quinone path [mediated by aldo-keto reductase (AKR) enzymes], and (3) the radical cation path [mediated by CYP peroxidase]. In the case of BP, the major diol epoxide metabolite was identified as (+)-*anti*-BPDE (Figure 1). BP-7,8-Dihydrodiol, the metabolic precursor of (+)-*anti*-BPDE, is also a substrate for AKR-mediated activation to BP-7,8-catechol. This catechol enters into a redox cycle with O_2 to form BP-7,8-dione (BPQ) and generate reactive oxygen species (ROS) that attack DNA.[8,9] BPQ also reacts with DNA at dGua and dAde sites to form *stable* and *depurinated* adducts.[10,11] The *o*-quinone mechanism parallels AKR-mediated activation of estrogens to carcinogens.[12] The radical cation mechanism involves oxidation of PAHs by CYP peroxidase to generate PAH radical cations that interact with DNA to form depurinated adducts.[13]

Determination of the relative importance of these competing pathways in human cancer requires synthetic access to the various adducts formed by reaction of the active PAH metabolites with DNA. The structures of the adducts formed by PAH diol epoxides with dAde and dGua are well-established,[5,6] and satisfactory methods for their synthesis have been described.[5,14] Syntheses of the stable adducts of the PAH *o*-quinones with dAde and dGua have also recently been reported.[15] However, the depurinated adducts formed by the PAH radical cations are not readily accessible to most biological investigators. The only reported method of synthesis was via reaction of short-lived PAH radical cations with 2′-deoxyribonucleosides or nucleobases.[16−18] The PAH radical cations were generated in situ from the PAHs by electrochemical oxidation[16,17] or by one-electron oxidation of the parent PAHs with iodine (with or without added $AgClO_4$).[18] This synthetic method affords complex mixtures of products arising from the relatively indiscriminant attack of the reactive PAH radical cations at numerous sites in the purine substrates. The yields of the biologically relevant adducts tend to be low, and the types and relative ratios of the adducts formed differ from those formed in vivo.[19−21]

The principal adducts formed by one-electron oxidation of benzo[*a*]pyrene by rat liver microsomes in vitro[19] and in mouse skin[20] were identified as the C^8-guanine and N^7-guanine adducts (6-BP-8-Gua and 6-BP-7-Gua) and the N^7-adenine and N^3-adenine adducts (6-BP-7-Ade and 6-BP-3-Ade) (Figure 2). Metabolism of the highly potent PAH carcinogen dibenzo[*def*,*p*]-chrysene (DBC)[22] by the radical cation pathway was reported to furnish structurally related adducts in somewhat different ratio.[21]

To make the depurinated adducts of the PAH radical cations more readily available for biological and mechanistic investigations, we undertook to develop improved methods for their preparation. We now report an efficient new synthesis of the C^8-linked guanine and adenine adducts of PAHs. The compounds synthesized include the adducts of the PAH carcinogens BP (6-BP-8-Gua and 6-BP-8-Ade) (Figure 2) and DBC (10-DBC-8-Gua and 10-DBC-8-Ade) (Figure 3).

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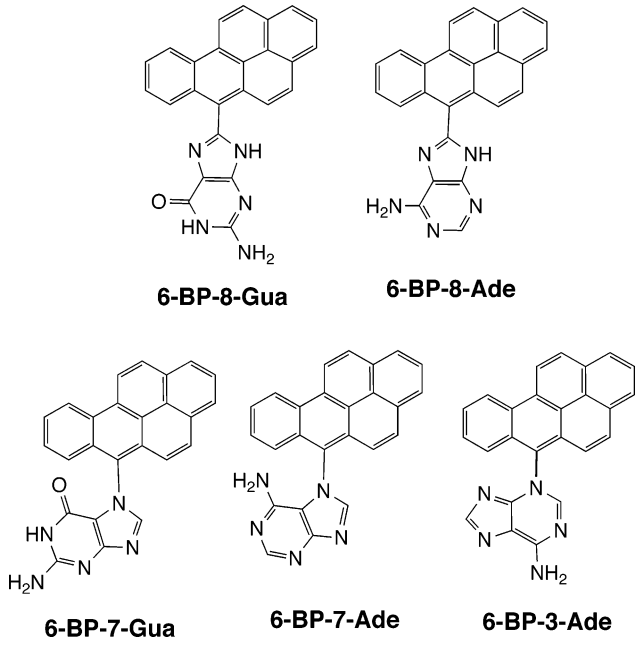


FIGURE 2. Depurinated adducts formed by reaction of benzo[*a*]pyrene (BP) radical cation at guanine and adenine sites in DNA.

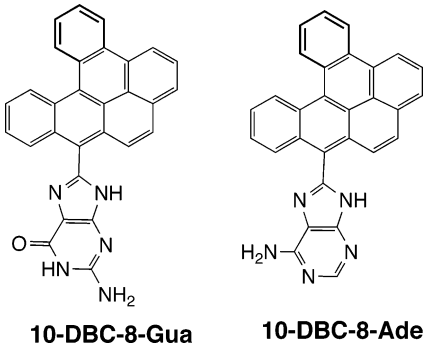


FIGURE 3. Depurinated C^8-guanine and C^8-adenine adducts formed by reaction of dibenzo[*def*,*p*]chrysene (DBC) with DNA.

Results

Initial investigations of potential synthetic routes to the C^8-arylpurine adducts focused on Suzuki−Miyaura coupling of the readily available 8-bromopurine nucleosides with PAH boronic acids (Scheme 1). Preliminary studies were carried out with pyrene 1-boronic acid (**1**). Prior reports[23] that **1** underwent palladium-catalyzed cross-coupling with the 8-bromo derivatives of 2′-deoxyguanosine (8-Br-dGua) and 2′-deoxyadenosine (8-Br-dAde) in the presence of phosphine ligands in aqueous acetonitrile were confirmed. Removal of the sugar by treatment of the initially formed adducts (**2a** and **3a**) with phosphoric acid afforded the C^8-(1-pyrenyl)guanine (**2b**) and C^8-(1-pyrenyl)-adenine (**3b**) adducts in moderate yields. Attempted synthesis of the C^8-guanine adduct by direct cross-coupling of 8-bromoguanine with **1** gave **2b** in only low yield.

Attempted extension of this approach to the synthesis of the corresponding C^8-guanine and C^8-adenine adducts of BP met with difficulty. BP 6-boronic acid (**4**) was synthesized from

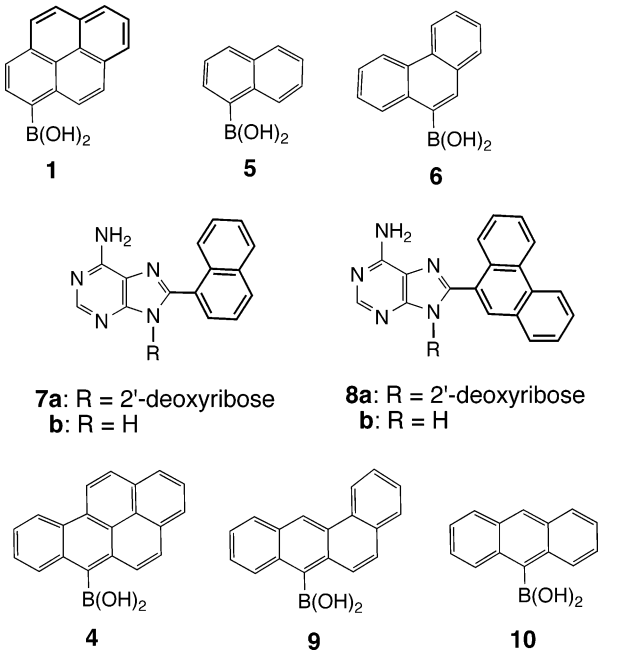
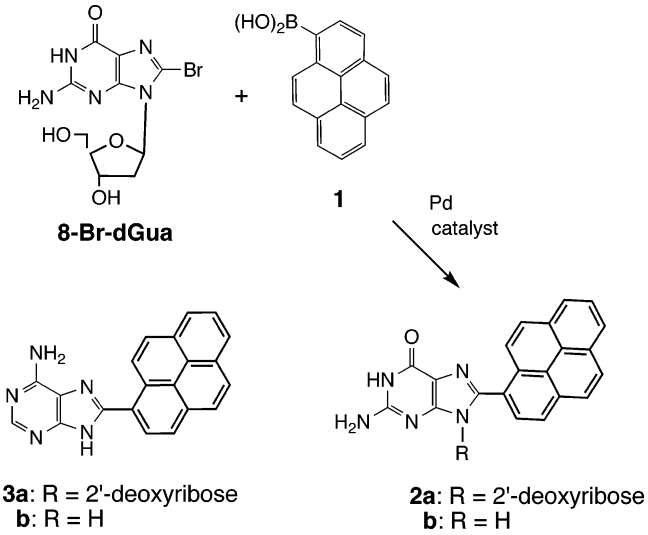


FIGURE 4. Boronic acids **1**, **5**, and **6** undergo Pd-catalyzed coupling with 8-bromo-2′-deoxyguanosine to furnish coupled adducts (**2a**, **7**, **8**), but boronic acids **4**, **9**, and **10** fail to participate in similar reactions.

SCHEME 1



6-bromo-BP via reaction with *n*-BuLi and trimethylborate followed by hydrolysis (Figure 4). However, the yield of **4** was poorly reproducible (optimum ∼50%). Indeed, it was reported that attempted synthesis of **4** by this method failed.[24] Attempts to couple 8-Br-dGua or 8-Br-dAde with **4** by the procedure employed for the C^8-(1-pyrenyl) adducts were unsuccessful, as was the use of Pd catalysts reported to favor coupling of hindered boronic acids.[25] The principal product obtained in all cases was BP itself.

To gain insight into the influence of structural factors on the abilities of arylboronic acids to participate in Pd-catalyzed coupling with halopurines, analogous reactions of several additional arylboronic acids were examined. Naphthalene 1-bo-

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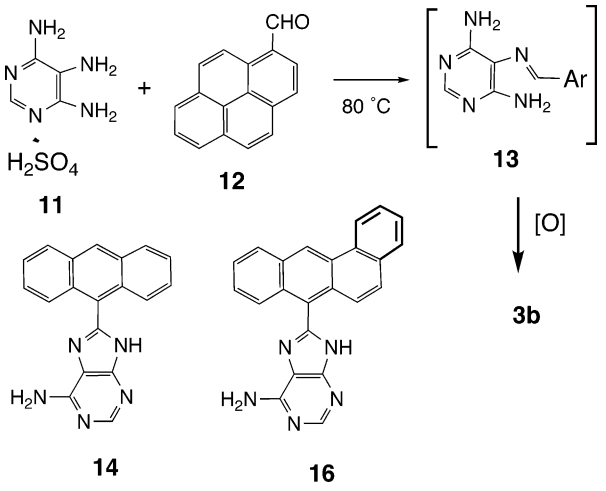
SCHEME 2



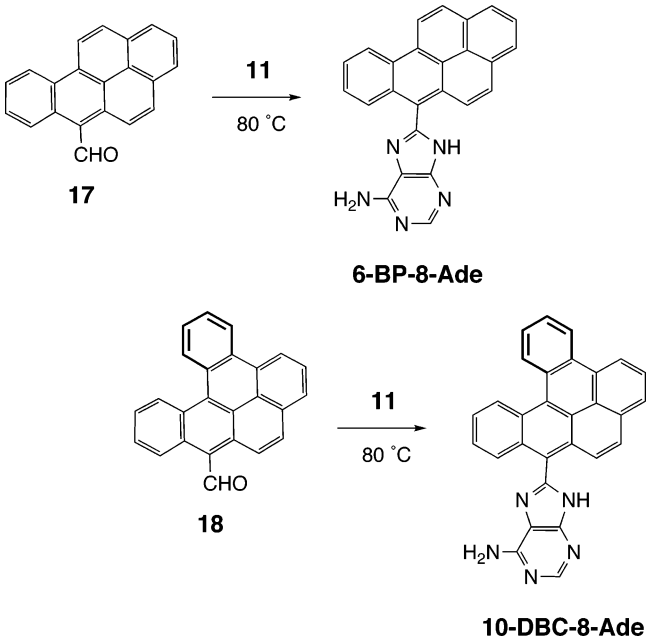
ronic acid (**5**) and phenanthrene 9-boronic acid (**6**) reacted with 8-Br-dA to furnish the *C*[8]-dA coupled adducts (**7a** and **8a**) (Figure 4). Conversely, the boronic acid derivatives of benz[*a*]anthracene (**9**) and anthracene (**10**) failed to engage in analogous coupling with either 8-Br-dA or 8-Br-dG, affording instead the parent PAHs as principal products.

The most obvious difference between aryboronic acids that participate in coupling (**1**, **5**, **6**) and those that fail to do so (**4**, **9**, **10**) is the greater steric hindrance of the latter at the reaction site. The arylboronic acids that do not engage in coupling are distinguished by the presence of fused aromatic rings flanking both sides of the boronic acid group. The findings indicate that the hindered arylboronic acids underwent hydrolytic deboronation[26] to yield the parent PAHs. The failure of coupling to take place appears to be the net consequence of (1) steric retardation of the rate of coupling and (2) acceleration of the rate of hydrolysis of the boronic acid groups in the reactive *meso*-region positions of the PAHs. The hydrolytic instability of BP 6-boronic acid (**4**) relative to pyrene 1-boronic acid (**1**) was confirmed by comparison of their extents of hydrolysis under the conditions employed in the coupling experiments. Under these conditions with the Pd catalyst present and the 8-bromopurine nucleoside absent from the reaction mixture, hydrolysis of **4** was complete in less than 10 min. In striking contrast, pyrene 1-boronic acid remained essentially unchanged under identical conditions for 16 h.

Investigation of the Suzuki coupling method was discontinued in favor of a more promising alternative synthetic strategy. This new approach entailed reaction of PAH aldehyde derivatives with di- or triamine precursors of the purine ring systems (Scheme 2). Precedent was provided by prior reports of synthesis of analogous phenyl-substituted derivatives of heterocyclic compounds by similar methods.[27]

Pyrene-1-carboxaldehyde (**12**) reacted readily with 4,5,6-triaminopyrimidine sulfate (**11**) in DMSO at 80 °C to furnish directly the *C*[8]-pyrenyl adduct of adenine (**3b**) in a single step (68%). Synthesis of imidazole compounds by this method is known to proceed via initial formation of a Schiff base, such as **13**, followed by cyclization and air oxidation.[27] Due to the symmetry of **11**, the structure of the final product (**3b**) is independent of which of the three amino groups reacts initially to generate a Schiff base. The structural assignment of **3b** was consistent with its ^{1}H and ^{13}C NMR spectra as well as with the NMR spectral data for this compound synthesized via the alternative Suzuki coupling method. The ^{1}H NMR spectrum of **3b** showed only a single amino group, confirming that cyclization had taken place. The ^{1}H NMR spectrum also exhibited an exchangeable peak at δ 13.5 ppm, corresponding to the N^9-proton of adenine.

SCHEME 3



To assess the utility of the method for the synthesis of analogous adducts of sterically hindered PAHs, similar reactions were carried out with the aldehyde derivatives of anthracene and benz[*a*]anthracene (Scheme 2). Anthracene-9-carboxaldehyde reacted readily with **11** in DMSO at 90 °C to furnish the *C*[8]-anthracenyladenine adduct (**14**) in good yield (64%). A longer time (2 days) was required for completion of the reaction than for reaction of **12** with **11** (overnight). Anthracene-9-carboxylic acid failed to react with **11** under identical conditions.[28] The structural assignment of **14** was consistent with its ^{1}H NMR spectrum, which showed it to be an N^9-protonated adenine isomer. Vilsmeier−Haack formylation of benz[*a*]anthracene with $POCl_3$ and DMF afforded BA-7-carboxaldehyde (**15**), and it reacted with **11** in DMSO to furnish the *C*[8]-benz[*a*]anthracenyladenine adduct (**16**) in good yield (94%) (Scheme 2). The ^{1}H and ^{13}C NMR spectra of the adduct were in good agreement with the N^9-protonated adenine isomer structure.

Successful synthesis of the sterically hindered *C*[8]-linked adenine adducts **14** and **16** from the related PAH aldehyde derivatives supported extension of this synthetic approach to the analogous adducts of BP and DBC (Scheme 3). Formylation of BP by the usual method gave benzo[*a*]pyrene-6-carboxal-

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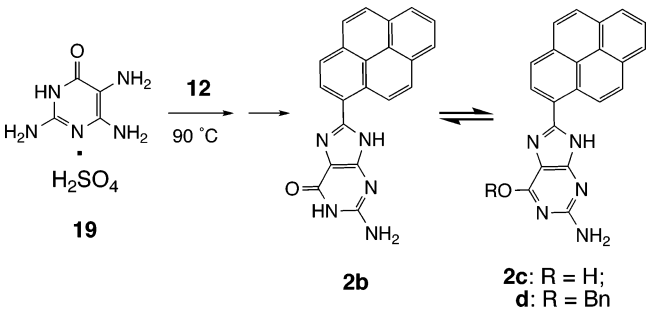
SCHEME 4



dehyde (**17**), and reaction of **17** with **11** took place readily to furnish the C^8-benzo[*a*]pyrenyladenine adduct (6-BP-8-Ade) in good yield (88%). The ^{1}H and ^{13}C NMR spectra of 6-BP-8-Ade were in agreement with the structural assignment. Formylation of DBC with $POCl_3$ and DMF gave DBC-10-carboxaldehyde (**18**), and reaction of **18** with **11** in DMSO furnished the C^8-DBC adduct (10-DBC-8-Ade) (Scheme 3) in good yield (75%). The physical and spectral properties of 10-DBC-8-Ade were in excellent agreement with its structural assignment. The 6-BP-8-Ade and 10-DBC-8-Ade adducts are the first examples of the synthesis of C^8-linked adenine adducts of PAH carcinogens.

Synthesis of the analogous C^8-linked guanine adducts was accomplished by modification of this methodology (Scheme 4). 6-Hydroxy-2,4,5-triaminopyrimidine sulfate (**19**) was employed as the precursor of the guanine ring system. Reaction of **19** with pyrene-1-carboxaldehyde (**12**) took place smoothly in DMSO to furnish 8-(pyren-1-yl)-2′-guanosine (**2a**), which was converted to 8-(pyren-1-yl)-2′-guanine (**2b**).

The ^{1}H NMR spectrum of **2b** was consistent with its structural assignment, with the minor difference that several additional smaller signals shifted slightly from the main peaks were also observed. These peaks were indicative of the presence of a minor amount of a second isomer (ratio of isomers ∼4:1). The major isomer exhibited an exchangeable proton signal at δ 6.26 ppm, consistent with its assignment as the N^9-protonated isomer of the keto tautomer of guanine (**2b**). The minor isomer was assumed to be its enol tautomer (**2c**). Attempts to separate the tautomers were unsuccessful, indicating that the tautomers are in dynamic equilibrium. In addition, the ^{1}H NMR spectrum of **2b** prepared by coupling of pyrene 1-boronic acid with 8-bromo-2-deoxyguanosine followed by deglycosylation also exhibited similar duplicate sets of peaks in the same ratio (4:1).

Additional support for the existence of **2** as a pair of interconvertible tautomers (**2b**,**c**) was provided by variable-temperature ^{1}H NMR experiments. As the temperature of the mixture was increased, the distinctive character of the individual tautomeric signals diminished, and at ∼120 °C only a single set of peaks was evident. As the temperature of the sample was allowed to cool back to ambient temperature, the characteristic signals of the individual tautomers reappeared. Further supporting evidence was provided by benzylation of the mixture with benzyl chloride and pyridine. The benzyl ether derivative **2d** was obtained as the sole product. Its ^{1}H NMR spectrum was in agreement with structure **2c**, and the chemical shifts of the guanine proton signals were closely similar to those of the minor tautomer **2b**.

Analogous reactions of anthracene-9-carboxaldehyde and benz[*a*]anthracene-7-carboxaldehyde with **19** also took place readily in DMSO to furnish the corresponding 8-(9-anthracenyl)-guanine adduct (**20**) and the 8-(7-benz[*a*]anthracenyl)guanine adduct (**21**) (Figure 5) in yields of 70% and 49%, respectively. The ^{1}H and ^{13}C NMR spectra of **20** and **21**, both of which are new compounds, were consistent with their structural assignments. As in the case of the C^8-pyrenylguanine adduct (**2b**), these adducts were obtained as mixtures of tautomers (∼4:1) with the keto form of guanine predominating.

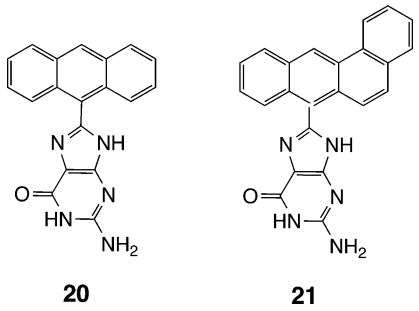


FIGURE 5. 8-(9-Anthracenylguanine (**20**) and 8-(7-benz[*a*]anthracenyl)guanine (**21**).

Syntheses of the C^8-guanine adducts of the carcinogenic PAHs benzo[*a*]pyrene and dibenzo[*def*,*p*]chrysene were similarly accomplished. Thus, benzo[*a*]pyrene-6-carboxaldehyde (**17**) readily entered into reaction with **19** in DMSO to furnish the C^8-benzo[*a*]pyrenylguanine adduct (6-BP-8-Gua) (Figure 2) in 75% yield. Analogous reaction of dibenzo[*def*,*p*]chrysene-10-carboxaldehyde (**17**) with **19** in DMSO provided the C^8-dibenzo[*def*,*p*]chrysenylguanine adduct (10-DBP-8-Gua) (Figure 3) (70%). The 6-BP-8-Gua and 10-DBP-8-Gua adducts were obtained, as in the case of the other C^8-PAH-guanine adducts, as mixtures of guanine tautomers in ∼4:1 ratio. The ^{1}H NMR spectrum of the 6-BP-8-Gua adduct was in good agreement with the NMR spectral data reported for 6-BP-8-Gua obtained from reaction of the BP radical cation with guanine.[29] Although formation of only the keto tautomer of guanine was mentioned in the early work, the published ^{1}H NMR spectrum of 6-BP-8-Gua clearly shows the presence of both the keto and the enol tautomers.

Discussion

An efficient new synthesis of C^8-arylpurines with specific application to the synthesis of the depurinated C^8-aryladenine and C^8-arylguanine adducts formed by radical cation metabolites of carcinogenic PAHs is reported. This synthetic approach entails direct reaction between a polycyclic aromatic aldehyde derivative and a suitable triamine precursor of the purine compound. The polycyclic arylaldehyde precursors that were not available from commercial sources were synthesized by Vilsmier−Haack formylation of the parent PAHs. The polycyclic arylaldehydes reacted readily with 4,5,6-triaminopyrimidine sulfate (**11**) to furnish the corresponding C^8-aryladenine adducts in good yields. Analogous reactions of the same polycyclic arylaldehydes with 6-hydroxy-2,4,5-triaminopyrimidine sulfate (**19**) provided equally convenient synthetic access to the corresponding C^8-arylguanine adducts (Scheme 5).

Synthesis of C^8-arylpurine adducts from reaction of arylaldehydes with the di- or triamine precursors of the purine ring system appears to be a method of broad scope. This synthetic

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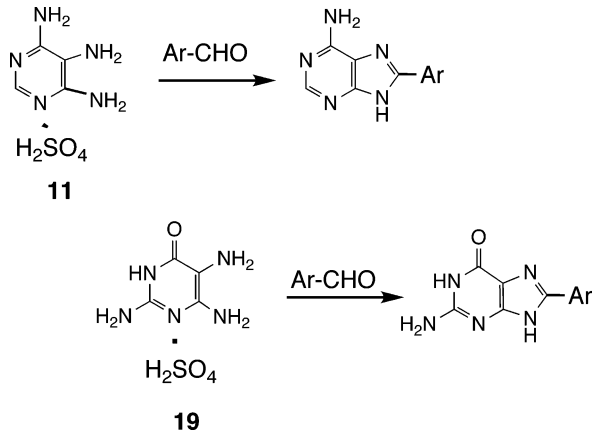
SCHEME 5



approach was successful for all the PAH compounds investigated, including even the sterically crowded adducts of the carcinogenic PAHs benzo[*a*]pyrene and dibenzo[*def*,*p*]chrysene. The *C*8-aryladenine and the *C*8-arylguanine adducts of both BP (Figure 2: 6-BP-8-Ade and 6-BP-8-Gua) and DBC (Figure 3: 10-DBC-8-Ade and 10-DBC-8-Gua) were obtained in good yields by this method. The 6-BP-8-Ade and 10-DBC-8-Ade adducts are the first examples of the *C*8-aryladenine adducts of any PAH carcinogen to be synthesized. The corresponding *C*8-arylguanine adducts, 6-BP-8-Gua and 10-DBC-8-Gua, were previously synthesized in low yields by reaction of the PAH radical cation intermediates generated in situ with guanine or 2′-deoxyguanosine.[16−18] The new synthetic approach reported herein is operationally simpler, provides the pure *C*8-arylpurine adducts in superior overall yield, and is more suitable for preparative scale synthesis.

Benzo[*a*]pyrene and dibenzo[*def*,*p*]chrysene[22] are ubiquitous environmental pollutants. Benzo[*a*]pyrene has been most intensively investigated,[1,2,5] and it is commonly employed as a standard for analysis of PAHs in the environment. BP is a component of cigarette smoke and it is strongly implicated in the causation of lung cancer.[1,2,4] Dibenzo[*def*,*p*]chrysene is reported to be the most potent PAH carcinogen in rodent bioassays.[30] It is present in cigarette smoke condensate,[31] in vehicle exhaust condensate,[31] in the particulate matter formed by combustion of smoky coal,[32] and in soil and sediment samples.[33] Development of efficient methods for synthesis of the *C*8-arylguanine and *C*8-aryladenine adducts of BP and DBC is expected to facilitate research to determine the relative importance of the radical cation pathway in relation to other mechanisms of PAH carcinogenesis.

The alternative synthetic route to the *C*8-aryl adducts of the purine bases via Suzuki−Miyaura coupling of PAH boronic acids with 8-bromopurine nucleosides (Scheme 1) was found to be less generally useful. This is primarily a consequence of the restricted solubilities of the reactants: the nucleosides are strongly hydrophilic and the PAHs are strongly lipophilic. Simultaneous solubilization of both reactants requires a semi-aqueous medium and a relatively polar solvent, such as acetonitrile. Unfortunately, the boronic acid derivatives of BP and other carcinogenic PAHs are relatively susceptible to hydrolytic deboronation, and there is evidence that their hydrolysis is catalyzed by the Pd catalysts used for coupling. Thus, the utility of the Suzuki−Miyaura coupling method for synthesis of *C*8-arylpurine derivatives is restricted to arylboronic acids that are resistant to hydrolysis.

Synthesis of *C*8-arylpurine adducts from arylaldehyde precursors offers significant advantages over older synthetic methods involving reaction of PAH radical cations generated by chemical or electrochemical methods. Reactions of PAH radical cations with 2′-deoxyribonucleosides or nucleobases affords low yields of adducts of biological interest along with mixtures of secondary products that are difficult to separate. In contrast, the synthetic route from arylaldehyde precursors provides good yields of the *C*8-aryl adducts of adenine and guanine uncontaminated by significant amounts of unwanted byproducts. Purification of the desired adducts is relatively straightforward, and the method is readily adaptable to preparation of *C*8-arylpurine adducts on virtually any scale. Although this investigation focused on adducts of PAH carcinogens, the method is not restricted to these types of adducts. In principle, it may be employed to synthesize virtually any *C*8-arylpurine derivative. It is likely that the method will also find useful applications in medicinal chemistry.

We are currently investigating improved methods for the synthesis of other depurinated adducts formed in reactions of PAH radical cations with DNA.

Experimental Section

General Procedure for Synthesis of Arylboronic Acids from Aryl Bromides. To a 500 mL round bottomed flask was added a solution of the PAH bromide (23.3 mmol) dissolved in 100 mL of anhydrous diethyl ether under an argon stream, then the solution was cooled in an ice bath. *n*-BuLi in hexane (93.4 mmol, 2.5 M, 37 mL, 4 equiv) was injected carefully, and the color became dark reddish-brownish. The solution was stirred at room temperature for 3 h, then it was cooled to 0 °C, and triisopropylborate (233 mmol, 54 mL) was added slowly. The solution was allowed to warm to room temperature, and stirred overnight. It was then cooled in an ice bath, 100 mL of 2 N HCl was added carefully, and stirring was continued for another 4 h. Diethyl ether (100 mL) was added, and the product was extracted into the ether layer. The combined ether layer was dried over $NaSO_4$ (3 g) for 4 h, filtered, and evaporated to dryness. The residue was triturated with hexane (100 mL), and the product was dried under vacuum.

Anthracene-9-boronic acid (10): yield 63%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 7.48−7.52 (m, 4H), 7.98−8.00 (m, 2H), 8.06−8.08 (m, 2H), 8.52 (s, 1H), 8.79 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) 125.0, 125.2, 125.9, 128.4, 129.0, 130.8, 132.7; EI-MS *m*/*e* 222.1 [M^+], HRMS calcd for $C_{14}H_{10}B_1O_2$ [M^-] 221.0774, found 221.0780, calcd [M^+] 222.0852, found 222.0851.

Benz[*a*]anthracene-7-boronic acid (9): yield 68%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 9.50 (s, 1H), 9.08 (d, J = 8.0 Hz, 1H), 8.96 (br, 2H), 8.32 (m, 1H), 8.14 (m, 1H), 8.01 (d, J = 7.7 Hz, 1H), 7.92 (d, J = 9.1 Hz, 1H), 7.83 (d, J = 9.2 Hz, 1H), 7.80 (t, J = 7.2, Hz, 1H), 7.73 (t, J = 7.4 Hz, 1H), 7.68 (m, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) 133.6, 131.8, 131.7, 131.6, 130.8, 129.2, 129.1, 128.8, 128.6, 128.2, 127.6, 127.4, 126.7, 126.0, 125.9, 123.7, 122.0. EI-MS *m*/*e* 222.1 [M^+], HRMS calcd for $C_{18}H_{13}B_1O_2$ [M^-] 271.0930, found 271.0939.

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Benzo[*a*]pyrene-6-boronic acid (4): yield 52%. Trimethylborate (6 equiv) was used instead of triisopropylborate. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 7.84−7.90 (m, 2H), 8.02−8.08 (m, 3H), 8.18 (d, 1H, J = 7.5 Hz), 8.29 (d, 1H, J = 7.5 Hz), 8.31 (d, 1H, J = 7.5 Hz), 8.33 (d, 1H, J = 8.0 Hz), 8.42 (d, 1H, J = 9.0 Hz), 8.97 (br, 2H), 9.24 (d, 1H, J = 8.0 Hz), 9.25 (d, 1H, J = 9.0 Hz); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 122.5, 123.5, 124.7, 124.7, 125.4, 126.0, 126.3, 126.6, 127.1, 127.2, 127.4, 129.2, 129.7, 130.5, 131.0, 131.1, 132.5; HRMS calcd for $C_{20}H_{12}B_1O_2$ [M$^-$] 295.0930, found 295.0924.

General Procedure for Synthesis of *C*^{8}-PAH-2′-deoxyadenosine or *C*^{8}-PAH-2′-deoxyguanosine Adducts by the Suzuki−Miyaura Coupling Method. To a 150 mL pyrex culture tube containing 10 mL of acetonitrile/H_2O (1:2, v/v) were added the PAH-boronic acid (1.12 mmol), $NaCO_3$ (160 mg, 1.5 mmol), TPPTS (29.6 mg, 0.052 mmol), $Pd(OAc)_2$ (4.4 mg, 0.02 mmol), and 8-bromo-2′-deoxyadenosine or 8-bromo-2′-deoxyguanosine (1.1 mmol). The tube was sealed and heated overnight at 80 °C with stirring. Water (10 mL) and 10% KH_2PO_4 (20 mL) were added, and the mixture was heated at 90 °C for 2 h. The solution was allowed to cool to room temperature, and further cooled in an ice bath for several hours. The precipitate was filtered and washed sequentially with 50 mL each of water, hexane, ether, and EtOAc, then dried in air.

8-(1-Naphthyl)-2′-deoxyadenosine (7a): yield 58%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 2.00 (br, 1H), 3.15 (br, 1H), 3.47 (br, 1H), 3.64 (m, 1H), 3.74 (br s, 1H), 4.32 (br, 1H), 5.09 (br, 1H), 5.74 (m, 2H), 7.51 (br s, 2H), 7.55−7.58 (m, 1H), 7.61−7.65 (m, 2H), 7.69−7.74 (m, 2H), 8.09 (J = 8 Hz, d, 1H), 8.19 (J = 9 Hz, d, 1H), 8.20 (s, 1H); HRMS calcd for $C_{20}H_{20}N_5O_3$ [M$^+$] 378.1566, found 378.1562.

8-(9-Phenanthryl)-2′-deoxyadenosine (8a): yield 80%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 1.99 (br, 1H), 3.47 (br, 1H), 3.64 (br, 1H), 3.72 (s, 1H), 4.30 (br, 1H), 5.05 (br, 1H), 5.78 (br, 2H), 7.55 (br, 2H), 7.66−7.69 (m, 2H), 7.73−7.81 (m, 2H), 7.83−7.86 (m, 1H), 8.14 (d, 1H), 8.15 (s, 1H), 8.22 (s, 1H), 8.96 (J = 8.5 Hz, d, 1H), 9.00 (J = 8.5 Hz, d, 1H); HRMS calcd for $C_{24}H_{21}N_5O_3$ [M$^+$] 428.1723, found 428.1736.

8-(1-Pyrenyl)-2′-deoxyguanosine (2a): yield 65%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 1.94 (m, 1H), 3.02 (br s, 1H), 3.39 (m, 1H), 3.47 (m, 1H), 3.62 (s, 1H), 4.14 (s, 1H), 5.00 (br, 1H), 5.15 (br, 1H), 5.80 (br, 1H), 6.84 (br s, 2H), 8.02 (d, 1H, J = 9 Hz), 8.13−8.17 (m, 2H), 8.25−8.33 (m, 3H), 8.37 (d, 1H, J = 7.5 Hz), 8.40 (d, 1H, J = 7.5 Hz), 8.43 (J = 8 Hz, d, 1H), 11.82 (br s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 158.0, 154.4, 152.1, 145.6, 132.0, 131.2, 130.7, 130.5, 129.0, 128.9, 128.9, 127.6, 127.1, 126.4, 126.2, 125.3, 125.0, 124.8, 124.1, 123.9, 118.0, 88.2, 85.3, 71.6, 62.5, 37.5; HRMS calcd for $C_{26}H_{22}N_5O_4$ [M$^+$] 468.1672, found 468.1651.

Synthesis of C^8-Aryladenine and C^8-Arylguanine Adducts. Deglycosylation of 2′-deoxyribonucleoside adducts was conducted by the procedure reported in ref 23b.

8-(1-Naphthyl)adenine (7b): yield 83%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 7.24 (br s, 2H), 7.61−7.63 (m, 2H), 7.66 (t, 1H, J = 8.0 Hz), 7.97 (d, 1H, J = 7.0 Hz), 8.04 (d, 1H, J = 8.5 Hz), 8.08 (d, 1H, J = 8.0 Hz), 8.17 (s, 1H), 9.05 (d, 1H, J = 7.5 Hz), 13.32 (s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 155.69, 152.62, 151.26, 148.19, 133.55, 130.36, 130.16, 128.37, 127.97, 127.09, 126.36(2), 125.23, 119.70; HRMS calcd for $C_{15}H_{12}N_5$ [M$^+$] 262.1093, found 262.1105.

8-(9-Phenanthryl)adenine (8b): yield 98%. ^{1}H NMR (DMSO-d_6) δ 7.30 (br s, 2H), 7.68−7.75 (m, 2H), 7.77−7.85 (m, 2H), 8.09 (d, 1H, J = 8 Hz), 8.19 (s, 1H), 8.33 (s, 1H), 8.91 (d, 1H, J = 8 Hz), 8.96 (d, 1H, J = 8 Hz), 9.00 (d,1H, J = 8.5 Hz), 13.44 (br s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 155.75, 152.74, 151.24, 148.17, 130.38, 130.24, 129.57, 129.23, 129.00, 128.26, 127.46, 127.31, 127.05, 126.12, 123.29, 123.01, 119.68.

8-(1-Pyrenyl)adenine (3b): yield 68%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 7.38 (br s, 2H), 8.13−8.51 (m, 9H), 9.41 (J = 9.3 Hz, d, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 152.60, 130.89, 130.63, 130.31, 128.62(3), 127.41, 127.37, 127.31, 126.73, 126.25, 126.0, 125.70, 125.57, 125.10, 124.87, 124.25, 124.15, 123.78, 123.66; APCI-MS *m*/*e* 336.1 [M$^+$].

8-Phenylguanine: yield 83%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 6.41 (br s, 2H), 7.44−7.48 (m, 3H), 7.98 (J = 7.2 Hz, d, 2H), 10.59 (br s, 1H), 12.82 (br s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 157.03, 157.73, 153.60, 145.0, 130.28, 129.03, 126.5, 125.5, 117.61, 129.1; HRMS calcd for $C_{19}H_{14}N_5$ [M$^+$] 312.1249, found 312.1254.

8-(1-Pyrenyl)guanine (2b): yield 91%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 6.48 (br s, 2H), 8.12 (t, 1H, J = 7.6 Hz), 8.20−8.43 (m, 7H), 9.52 (d, 1H, J = 7.1 Hz), 10.69 (br s, 1H), 13.05 (br s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 156.89, 153.70, 153.29, 145.08, 131.29, 130.99, 130.69, 128.60, 128.50, 127.71, 127.65, 126.98, 126.59, 126.11, 125.78, 125.44, 125.14, 124.71, 124.56, 124.11, 118.17; HRMS calcd for $C_{21}H_{14}N_5O_1$ [M$^+$] 352.1198, found 352.1216.

7-Benz[*a*]anthracenecarboxaldehyde (15).[34] ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 11.48 (s, 1H), 9.89 (s, 1H), 9.09 (d, J = 8.1 Hz, 1H), 9.01 (d, 1H, J = 8.8 Hz), 8.79 (d, 1H, J = 9.6 Hz), 8.39 (d, 1H, J = 8.2 Hz), 8.04 d, 1H, J = 7.7 Hz), 8.01 (d, 1H, J = 9.7 Hz), 7.79−7.82 (m, 2H), 7.73−7.77 (m, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 193.6, 132.0, 131.2, 131.0, 131.0, 130.8, 130.1, 129.4, 128.9, 128.9, 128.6, 128.2, 127.6, 127.6, 126.1, 125.9, 123.6, 122.8, 121.5; HRMS calcd for $C_{19}H_{13}O_1$ [M$^+$] 257.0966, found 257.0966.

6-Benzo[*a*]pyrenecarboxaldehyde (17). To a solution of benzo[*a*]pyrene[35] (1 g, 4 mmol) in DMF (10 mL) in a 150 mL pyrex culture tube were added $POCl_3$ (1.2 g) and *N*-methylformanilide (1.2 g). The screw cap was sealed, and the reaction tube was heated at 90 °C overnight. The reaction mixture was cooled and washed with 40 mL of diethyl ether. The red slurry was recovered and mixed with Na_2CO_3 (2.5 g/50 mL water) in a 150 mL beaker. The green precipitate that formed was filtered, washed with a copious amount of water, and dried in the air to furnish **16** essentially quantitatively: ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 7.96−7.98 (m, 2H), 8.18 (t, 1H, J = 7.6 Hz), 8.34 (d, 1H, J = 9.6 Hz), 8.41 (d, 1H, J = 7.3 Hz), 8.54 (d, 1H, J = 7.7 Hz), 8.68 (d, 1H, J = 9.1 Hz), 9.06 (d, 1H, J = 9.6 Hz), 9.27−9.30 (m, 1H), 9.35−9.39 (m, 2H), 11.61 (s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 194.9, 131.7, 131.4, 131.3, 131.1, 130.7, 129.7, 128.9, 128.4, 127.9, 127.4, 127.3, 127.1, 126.8, 124.7, 124.0, 123.8, 123.48, 122.8, 122.6, 121.8; EI-MS *m*/*e* 280.1 [M$^+$]; HRMS calcd for $C_{21}H_{12}O_1$ [M$^+$] 280.0888, found 280.0872

10-Dibenzo[*def*,*p*]chrysenecarboxaldehyde (18). To a solution of dibenzo[*def*,*p*]chrysene[36] (100 mg, 0.33 mmol) in 1,2-dichlorobenzene (0.5 mL) in a 10 mL pyrex culture tube were added *N*-methylformanilide (0.11 g) and $POCl_3$ (0.11 g). The mixture was heated at 90 °C for 8 h and monitored by TLC. The mixture was poured into water (2 mL) and extracted with EtOAc (500 mL), and the organic layer was washed with water (3 × 100 mL) and dried over anhydrous Na_2SO_4. Evaporation of most of the solvent followed by filtration of the solid precipitate afforded **17** (96 mg, 88%) sufficiently pure for reaction: ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 11.58 (s, 1 H), 9.31 (d, J = 8.0 Hz, 1 H), 9.25 (d, J = 8.0 Hz, 1 H), 9.16 (d, J = 8.0 Hz, 1 H), 9.07 (dd, J = 8.0 and 5.0 Hz, 2 H), 8.94 (d, J = 8.0 Hz, 1 H), 8.39 (d, J = 8.0 Hz, 1 H), 8.29 (d, J = 10.0 Hz, 1 H), 8.20 (t, J = 8.0 Hz, 1 H), 7.98 (d, J = 8.0 Hz, 1 H), 7.94 (d, J = 8.0 Hz, 1 H), 7.86 (d, J = 8.0 Hz, 1 H), 7.84 (d, J = 8.0 Hz, 1 H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 194.6, 132.1, 131.8, 131.7, 131.5, 131.1, 129.4, 129.0, 128.8, 128.7, 128.3, 128.1, 127.7, 127.3, 126.3, 124.7, 124.6, 124.0, 123.2, 122.9, 122.6, 122.3; HRMS calcd for $C_{25}H_{14}O$ [MH$^+$] 331.1123, found 331.1135.

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General Procedure for Synthesis of *C*[8]-Aryladenine and -guanine Adducts from PAH Aldehydes. The arylaldehyde (59.4 mg, 0.18 mmol) and 4,5,6-triaminopyrimidine sulfate (41 mg, 0.18 mmol) and DMSO (2 mL) were placed in a 20 mL pressure tube and heated at 90 °C for 2 h with stirring. The reaction mixture was poured into a 50 mL round bottomed flask and washed with methanol. A small amount of silica gel was added to the flask, and the solvent was removed under reduced pressure. The residue was purified by chromatography on a column of silica gel eluted with CH_3OH/CH_2Cl_2 (1:10) to afford the pure product.

8-(9-Anthracenyl)adenine (14): yield 64%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.26 (br, 1H), 8.73 (s, 1H), 8.15 (s, 1H), 8.09 (d, J = 8.4 Hz, 2H), 7.59 (d, J = 8.0 Hz, 2H), 7.46 (t, J = 7.8 Hz, 2H), 7.42 (t, J = 7.8 Hz, 2H), 7.24 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 151.5, 153.0, 152.1, 141.9, 131.0, 129.3, 128.9, 127.3, 126.1, 125.8, 125.6, 120.0; HRMS calcd for $C_{19}H_{13}N_5$ [MH$^+$] 312.1249, found 312.1257.

8-(7-Benz[*a*]anthracenyl)adenine (16): yield 75%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.59 (br, 1H), 9.70 (s, 1H), 9.06 (d, J = 8.0 Hz, 1H), 8.34 (d, 1H, J = 8.0 Hz), 8.22 (s, 1H), 7.93 (d, 1H, J = 7.5 Hz), 7.72−7.79 (m, 2H), 7.63−7.69 (m, 3H), 7.58 (d, J = 6.5 Hz, 1H), 7.45 (d, 1H, J = 9.0 Hz), 7.30 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 154.5, 151.2, 150.9, 148.0, 131.4, 131.4, 131.3, 130.2, 130.1, 129.3, 129.1, 129.0, 128.3, 128.2, 128.1, 127.8, 126.6, 125.9, 125.6, 125.1, 124.4, 123.9, 119.4; HRMS calcd for $C_{23}H_{16}N_5$ [M$^+$] 362.1406, found 362.1400.

8-(1-Pyrenyl)adenine (3b): yield 68%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.52 (br, 1H), 9.39 (d, J = 9.3 Hz, 1H), 8.47 (d, J = 8.0 Hz, 1H), 8.38 (d, J = 8.0 Hz, 1H), 8.32 (d, J = 3.7 Hz, 1H), 8.30 (d, J = 3.4 Hz, 1H), 8.26 (d, J = 9.4 Hz, 1H), 8.18−8.24 (m, 3H), 8.08 (t, J = 7.0 Hz, 1H), 7.31 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 152.9, 132.0, 131.2, 130.6, 129.7, 129.4, 129.0, 128.9, 128.8, 127.7, 127.6, 127.5, 126.9, 126.7, 126.5, 126.2, 126.0, 125.1, 124.6, 124.5, 124.0; HRMS calcd for $C_{21}H_{13}N_5$ [MH$^+$], 336.1249, found 336.1267.

8-(6-Benzo[*a*]pyrenyl)adenine (6-BP-8-Ade): yield 88%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.58 (br, 1H), 9.23−9.26 (dd, J = 8.9, 8.3 Hz, 2H), 8.48 (d, 1H, J = 9.0 Hz), 8.37 (d, 1H, J = 7.8 Hz), 8.34 (s, 1H), 8.19 (d, 1H, J = 7.4 Hz), 8.04 (t, 1H, J = 8.8 Hz), 8.00 (d, 1H, J = 9.4 Hz), 7.91 (d, J = 8.2 Hz, 1H), 7.86 (t, 1H, J = 7.5 Hz), 7.75 (t, 1H, J = 7.5 Hz), 7.69 (d, 1H, J = 9.3 Hz), 7.47 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 156.3, 153.2, 151.9, 147.1, 131.3, 130.7, 130.6, 129.5, 129.5, 129.3, 128.6, 127.6, 127.2, 127.0, 126.9, 126.7, 126.3, 125.6, 124.5, 124.2, 123.9, 122.8, 122.5, 120.1; HRMS calcd for $C_{25}H_{15}N_5$ [MH$^+$] 386.1406, found 386.1398.

8-**(10-Dibenzo[*def*,*p*]chrysenyl)adenine (10-DBC-8-Ade):** yield 75%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.50 (s, 1 H), 9.17 (d, J = 8.0 Hz, 1 H), 9.12 (d, J = 8.0 Hz, 1H), 9.07 (d, J = 8.0 Hz, 1H), 9.02 (d, J = 8.0, 1H), 8.27 (s, 1H), 8.21 (d, J = 8.0 Hz, 1H), 8.08 (t, J = 8.0 Hz, 1H), 7.99 (d, J = 8.0 Hz, 1H), 7.97 (d, J = 8.0 Hz, 1H), 7.90−7.60 (m, 5H), 7.39 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 156.3, 153.2, 151.9, 146.9, 131.8, 131.5, 130.9, 130.3, 129.3, 129.1, 128.5, 128.2, 127.9, 127.6, 127.5, 127.4, 127.1, 126.5, 126.4, 125.1, 125.1, 124.7, 123.4, 122.6, 122.3, 120.2; HRMS calcd for $C_{29}H_{18}N_5$ [MH$^+$] 436.1552, found 436.1563.

8-(9-Anthracenyl)guanine (20): yield 70%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 12.79 (br, 1H), 10.71 (s, 1H), 8.77 (s, 1H), 8.16 (d, J = 8.1 Hz, 2H), 7.73 (d, J = 8.3 Hz, 2H), 7.54 (t, J = 6.8 Hz, 2H), 7.50 (t, J = 7.7 Hz, 2H), 6.44 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 157.3, 154.0, 153.4, 142.7, 131.1, 131.0, 128.9, 128.8, 127.0, 126.1, 126.0, 117.9; HRMS calcd for $C_{19}H_{13}N_5O$ [MH$^+$] 328.1198, found 328.1213.

8-(7-Benz[*a*]anthracenyl)guanine (21): yield 49%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 13.83 (br, 1H), 10.75 (s, 1H), 9.69 (s, 1H), 9.08 (d, 1H, J = 8.5 Hz), 8.35 (d, 1H, J = 8.5 Hz), 7.97(d, 1H, J = 8.0 Hz), 7.60−7.81 (m, 5H), 7.54 (d, 1H, J = 9.0 Hz), 6.49 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 157.0, 153.7, 153.0, 142.5, 131.2, 131.1, 131.0, 129.8, 129.7, 128.8, 128.6, 128.1, 127.9, 127.7, 127.6, 127.0, 126.4, 126.1, 125.5, 124.4, 124.0, 123.5, 117.6; HRMS calcd for $C_{23}H_{16}O_1N_5$ [M$^+$] 378.1355, found 378.1355.

8-(1-Pyrenyl)guanine (2b): yield 82%. ^{1}H NMR (500.1 MHz, DMSO-d_6) δ 6.48 (br s, 2H), 8.12 (t, J = 7.6 Hz, 1H), 8.20−8.43 (m, 7H), 9.52 (d, J = 7.1 Hz, 1H), 10.69 (br s, 1H), 13.05 (br s, 1H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 156.9, 153.7, 153.3, 145.1, 131.3, 131.0, 130.7, 128.6, 128.5, 127.7, 127.6, 127.0, 126.6, 126.1, 125.8, 125.4, 125.1, 124.7, 124.6, 124.1, 118.2; HRMS calcd for $C_{21}H_{14}N_5O$ [M$^+$] 352.1198, found 352.1216.

8-(6-Benzo[*a*]pyrenyl)guanine (6-BP-8-Gua): yield 75%. ^{1}H NMR (500.1 MHz DMSO-d_6) δ 12.94 (br, 1H), 10.78 (br, 1H), 9.26−9.30 (t, 2H), 8.52 (d, 1H, J = 9.1 Hz), 8.40 (d, 1H, J = 7.8 Hz), 8.22 (d, 1H, J = 7.3 Hz), 8.03−8.08 (m, 2H), 7.88−7.91 (m, 2H), 7.79 (t, 1H, J = 7.6 Hz), 7.70 (d, 1H, J = 9.3 Hz), 6.46 (br, 2H); ^{13}C NMR (125.8 MHz, DMSO-d_6) δ 171.0, 157.5, 154.0, 153.4, 143.4, 131.3, 130.7, 129.5, 129.3, 129.3, 128.4, 127.6, 127.6, 127.5, 127.2, 127.0, 126.8, 126.3, 125.7, 124.5, 124.4, 123.9, 122.8, 122.5, 117.8; ESI-MS *m*/*e* 402.4 [M$^+$]; HRMS calcd for $C_{25}H_{15}N_5O$ [M$^+$] 402.1355, found 402.1351.

8-(10-Dibenzo[*def*,*p*]chrysenyl)guanine (10-DBC-8-Gua): yield 70%. ^{1}HNMR (500.1 MHz, DMSO) δ 13.66 (s, 1H), 10.54 (s, 1H), 8.90 (t, J = 7.5 Hz, 2H), 8.84 (d, J = 7.5 Hz, 1H), 8.75 (d, J = 8.0 Hz, 1H), 7.98 (d, J = 7.5 Hz, 1H), 7.85 (t, J = 7.5 Hz, 1 H), 7.75 (d, J = 7.5 Hz, 2H), 7.70−7.45 (m, 5H), 6.24 (br s, 2H); ^{13}CNMR (125.8 MHz, DMSO) δ 157.5, 154.2, 153.5, 143.0, 132.0, 131.5, 131.0, 130.3, 129.3, 129.2, 129.0, 128.5, 128.2, 127.9, 127.6, 127.5, 127.2, 127.1, 126.6, 126.4, 125.5, 125.3, 124.7, 123.5, 122.7, 122.2, 118.1; HRMS calcd for $C_{29}H_{17}N_5O$ [M$^+$] 452.1511, found 452.1518.

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

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