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A photochemical strategy for aromatic nitrogen ortho-isomerization

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Anilines are essential functional groups in bioactive molecules. Their aromatic substitution pattern governs key physicochemical properties and thus biological activity. Accessing anilines with identical substituents but at alternative aromatic positions is highly desirable, but remains synthetically challenging. Herein, we report a synthetic strategy enabling the *ortho*-isomerization of aromatic nitrogen substituents. This approach leverages the visible light-mediated decomposition of aryl azides in the presence of a tailored thiophenol reagent to generate *ortho*-aminothiophenols. This transformation proceeds *via* nitrene generation and insertion, relocating the nitrogen group to its *ortho* position while installing the sulfur moiety at the *ipso* site. Subsequent oxidative cyclization yields a cyclic sulfonium intermediate, which can be cleaved or exploited as linchpins for divergent functionalization.

Introduction

Anilines are ubiquitous structural motifs in bioactive molecules. 1,2 The physicochemical properties and function of anilines are dictated by the nature and the positioning of their substituents.3-5 Changes in substitution patterns profoundly impact interactions with biological targets by modulating H-bonding, π -stacking, and other non-covalent interactions.^{6,7} Thus, positional isomers of anilines often display distinct biological profiles, underscoring the importance of accessing such variants during structure-activity relationship campaigns. Despite this relevance, accessing all possible isomeric aromatic compounds can still be challenging and, in most cases, each derivative requires a specifically designed and optimized de novo synthesis. This is due to the nature of traditional aromatic amination that follows a linear sequence of synthetic steps where functionality precursors (e.g. nitro group for reduction)8-10 or reactivity handles (e.g. halides for Buchwald-Hartwig cross-coupling) are installed via electrophilic aromatic substitution.11-14 Although more modern radical-based methods offer a more direct approach, they generally afford only a single isomer (para) and do not overcome the limitations in regioisomeric diversification (ortho - meta). 15-20 A highly desirable yet underexplored strategy involves the direct translocation of functional groups from one aromatic position to another. This would bypass traditional synthetic limitations and facilitate access to

Results and discussion

Design plan

In our earlier studies we demonstrated the synthesis of *ortho*-aminothiophenols, ³³ upon irradiating aryl azides I and sodium

high-value isomers. Unfortunately, methods that achieve such rearrangements are rare.21-23 The classical "halogen dance" strategy is limited to heteroaromatics24,25 and fails with benzenoids.26-29 Very recently, work by Yamaguchi and Lumb has explored new approaches to achieving aromatic ortho-isomerization. Yamaguchi developed a Pd-catalyzed process for the reconfiguration of ester groups A leveraging the thermodynamic equilibrium of η²-aryne-palladium complexes B during carbonylation and elimination steps (Scheme 1B).30,31 Lumb enabled the para to meta migration of OH groups in phenols C employing a designed sulfonyl hydrazide reagent to selectively generate diazonium intermediates D (Scheme 1B).32 These methods are restricted to single positional shifts without enabling further isomerization. Here, we report a synthetic protocol for nitrogen ortho-isomerization on benzene rings (Scheme 1C). Our approach uses aryl azides and a tailored thiophenol reagent under visiblelight photolysis to generate singlet nitrenes, which undergo regioselective insertion to yield ortho-aminothiophenols. These intermediates are converted to sulfonium salts, which serve as both removable handles and diversification platforms. This protocol enables the isomerization of the nitrogen atom from the para to the meta position, and from the meta to the ortho or para positions, potentially allowing controlled access to all possible isomers. The strategy is compatible with polysubstituted derivatives and has been applied to the isomerization of bioactive molecules.

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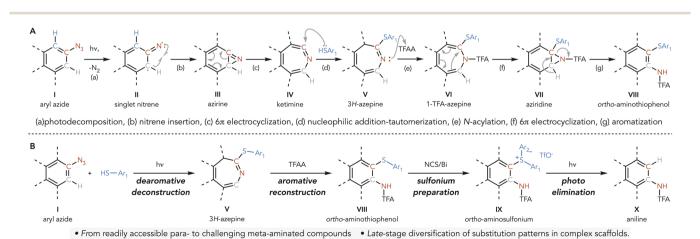
Scheme 1 (A) Group translocation-ortho isomerization logic. (B) Group translocation-ortho isomerization precedent. (C) This work.

thiolates with purple LEDs (l = 390 nm) (Scheme 2A).^{33–37} This process generates singlet aryl nitrenes II,38-43 which undergo Ninsertion to form azirines III.44 These intermediates partake in a 6π -electrocyclization event, leading to highly electrophilic ketimines IV. These intermediates can be trapped in situ with thiol nucleophiles and the resulting 1H-azepines45-47 readily isomerize to the thermodynamically stable 3H-azepines V.48-53 When treated with electrophiles like TFAA, V were converted into VII via the generation of antiaromatic VI, followed by 6π electrocyclization33,37,54,55 and aromatization. A key mechanistic aspect of this strategy is that the nitrogen undergoes orthoisomerization, with the thiol being selectively trapped at the original ipso position of the starting aryl azide I. Although this methodology effectively relocates the nitrogen atom, it fails to deliver rearranged anilines due to sulfur incorporation in the

final product. We envisioned that conversion of these aminothiophenols into sulfonium species followed by visible-lightmediated cleavage could provide a route to the rearranged anilines (Scheme 2B).

Reaction development

The success of this concept hinged on identifying a thiophenol capable of both trapping the ketimine intermediate and supporting subsequent sulfonium formation for the final cleavage step. Building on our previous work, we began by evaluating thiols 2a and 2b, which successfully enabled the formation of ortho-aminothiophenols.33 However, these intermediates failed to generate the corresponding sulfonium salts, likely due to the insufficient nucleophilicity of the sulfur moiety. In contrast, the more electron-rich thiol 2c afforded the desired sulfonium in high yield, but attempts at photoinduced cleavage were unsuccessful. These results clearly underscored the need for a single thiophenol reagent that could efficiently support all three steps of the sequence. To address this, we explored orthoaryl-substituted thiophenols, which were expected to form cyclic triaryl sulfoniums. These species were of particular interest due to their known propensity for undergoing photofragmentation with release of dibenzothiophene.56-59 Accordingly, we evaluated a series of biaryl thiophenols (2d-2h, Scheme 3). However, under standard conditions, these derivatives failed to participate in the nitrene-based insertion reaction. We found that their conversion to the corresponding sodium salts, required to activate the thiol for ketimine trapping, resulted in significant decomposition, presumably due to their high electron density and susceptibility to oxidative degradation. Since these thiophenols showed no reactivity in the absence of a base, we re-optimized the nitrene-insertion step. Rather than using a strong base, which can readily generate easily oxidized thiolates, we investigated the use of a milder base that could potentially also act as a nucleophilic activator. This base may trap the ketimine intermediate, thereby enabling its subsequent displacement by the sulfide. This approach proved effective, and DMAP was identified as the



Scheme 2 (A) Proposed mechanistic blueprint for the photochemical conversion of aryl azides into ortho-aminothiophenols. (B) Synthetic strategy design for nitrogen ortho isomerization.

Scheme 3 Optimized reaction conditions & thiol reagent design.

optimal additive to facilitate capture of intermediate **IV** by thiophenols **2d-2h**.

Among these, thiophenol 2h gave the highest conversion, whereas derivatives bearing para electron-donating (OMe, compounds 2d and 2f) or electron-withdrawing (CF₃, compounds 2e and 2g) substituents displayed reduced reactivity. With this improved protocol, we next examined sulfonium formation: upon treatment with MeOTf in DCM (conditions \mathbf{B}^2) only substrate 3ac was successfully converted to the desired product, which then unfortunately failed to undergo the subsequent step. On the other hand, with NCS as the electrophile and $Bi(OTf)_3$ as the Lewis acid (conditions B^1) we were able to obtain all the corresponding triaryl sulfonium salts, with^{60,61} the derivative derived from thiophenol 2h affording once again the highest yield. The final photocleavage step was evaluated using purple LEDs (l = 390 nm) in a MeOH-acetone mixture with Cs₂CO₃ as base. Notably, the efficiency of this transformation was highly sensitive to the substitution pattern on the sulfonium ring. While several sulfonium derivatives (2c, 2d, 2f and 2g) gave poor conversions, the compound derived from thiophenol 2h underwent clean photofragmentation to deliver the desired translocated aniline in quantitative yield. Although the origins of this enhanced reactivity remain unclear, thiophenol 2h consistently outperformed all other candidates across each of the three steps and was therefore selected as the optimal reagent for further scope exploration.

Scope of the nitrogen ring walk

With the optimized reaction conditions in hand, we explored the substrate scope using *para*-substituted aryl azides (1a-1y).

These azides, which are readily accessible from the corresponding *para*-substituted anilines as well as other feedstock materials (see SI material for details), serve as valuable precursors to *meta*-functionalized anilines, which are often synthetically challenging to access and, in fact, represent only a small fraction (7%) of commercially available compounds (see SI material for details).

As shown in Scheme 4A, a series of alkyl substituents were well tolerated, delivering products 5b-5e in overall good yields across the three-step sequence. Importantly, these substituents could incorporate a diverse range of functional groups, including HAT-activated benzyl (1e), α-methoxy (1h), nitrilesubstituted quaternary carbons (1g), and trifluoromethyl groups (1f, 1i). These products (5g-5i) were obtained in slightly reduced yields. Free alcohols, as in aryl azide 1j, afford 5j in 55% yield, with no observed self-condensation during the initial step, highlighting the protocol's chemoselectivity for thiol nucleophiles. Notably, the strongly electron-withdrawing para- CF_3 group (1f) was compatible, affording 5f in 47% overall yield. A boronic ester [B(pin)] substituent was also tolerated, furnishing product 5k, which is amenable to downstream crosscoupling functionalization. We next examined substrates bearing alkene (11) and aromatic (1m-1p) groups. These furnished the corresponding anilines (5l-5p) in moderate to good yields and demonstrated compatibility with para-substituents such as methoxy, iodine, and fluorine. This is particularly noteworthy given that para-substituted aromatics are known to suppress nitrene insertion due to electronic deactivation. 62 With meta-substituted azides, mixtures of ortho- and para-products were observed, consistent with the possibility of nitrene

1w

from Butamben

Scheme 4 Substrate scope of the nitrogen *ortho* isomerization. Solvent: # hexane, § diethyl ether, ‡ trifluorotoluene, † step A: trifluorotoluene 60 °C. Conditions: A: DMAP (1 eq.), 1,4-dioxane (0.05 M), hv = 390 nm, r.t., 16 h, then TFAA (4 eq.), r.t., 2h. B: NCS (1 eq.), Bi(OTf)3 (1 eq.), 1:11,4-dioxane/MeCN (0.033 M), r.t., 6 h. C: Cs2CO3 (1 eq.), 1:1 MeOH/Acetone (0.05 M), hv = 390 nm, r.t., 12 h. Yield: A = yield calculated based on the amount of thiol used, A and B = NMR yield, C = isolated yield.

from Aminoglutethimide

cyclization at either *ortho* position (Scheme 3).⁶³⁻⁶⁶ Nonetheless, the OMe-containing azide **1q** showed high regioselectivity for the ortho-isomer **5q**. In contrast, the *tert*-butyl derivative **1r** gave a near 1:1 mixture of *ortho* and *meta* products. Remarkably, shifting the solvent to trifluorotoluene and conducting the reaction at 60 °C significantly enhanced regioselectivity, yielding the *ortho*-isomer **5r** in a 4:1 ratio. (See the SI material for details of the optimization and comprehensive studies on

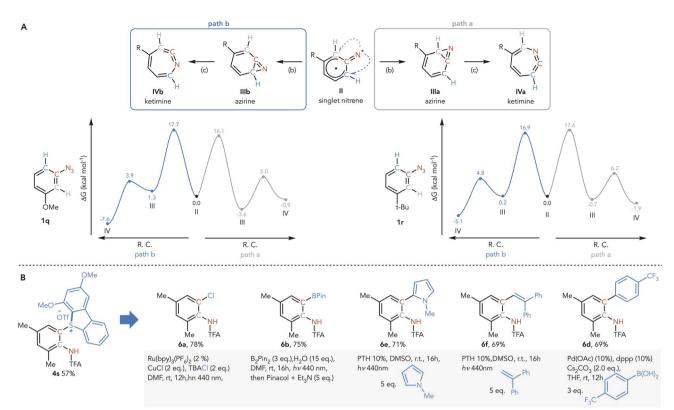
5w, 41%

other substrates) This observation highlights the decisive influence of solvent polarity and temperature on the reaction coordinate, allowing for fine-tuning of positional selectivity (Scheme 5A).

from Estrone

5y , 21%

We further extended the scope to polysubstituted azides. Symmetrical di-*meta*-substituted derivatives **1s** and **1t** yielded *ortho-para* anilines **5s** and **5t** in 54% and 32% yields, respectively, showcasing the method's tolerance toward electronically



Scheme 5 (A) Mechanistic analysis of regioselectivity. The numbers are the relative Gibbs free energies at UM06-2X/def2-QZVPP//def2-TZVP level of theory (kcal mol⁻¹). (B) Synthesis of *ortho*-anilines *via* sulfonium diversification.

rich systems. The bicyclic 6-azido-tetrahydronaphthalene 1u provided both regioisomers in comparable yields (36% and 52%). Trisubstituted azide 1v enabled the synthesis of the tetrasubstituted aniline 5v in 29% yield, an otherwise synthetically demanding structure that lies beyond the reach of conventional S_EAr or cross-coupling strategies.⁵ To further demonstrate the synthetic utility of our strategy, we applied it to azide derivatives of bioactive compounds. The local anesthetic butamben was converted into *meta*-butamben 5w in 27% yield. Similarly, the anticancer agent aminoglutethimide underwent clean para-to-meta isomerization to afford 5x in 55% yield. Estrone-derived azides yielded a 1:1 mixture of isomerized aminothiophenol intermediates. However, despite efficient sulfonium formation, photochemical cleavage conditions led exclusively to product 5y in 21% yield, with the other regioisomer undergoing complete decomposition.⁶⁷ It is worth noting that TFA protection is generally removed quantitatively after treatment with aqueous KOH wash, delivering the free anilines. This results in an overall isomerization from paraaniline (azide precursors) to meta-anilines.

Mechanistic analysis of regioselectivity

To gain deeper insight into the origins of regioselectivity in *meta*-substituted aryl azides such as **1q** and **1r**, we carried out DFT calculations on the two pathways (path a and path b) that proceed from the singlet nitrene (II) to the ketimine (IV) *via* the azirine (III), as the regioselectivity of the reaction is determined

by the nitrene insertion (Scheme 5A). For 1q, the nitrene-toazirine conversion (step b) is clearly favored along path a: the computed barrier is lower (16.1 vs. 17.1 kcal mol^{-1}), and the resulting azirine intermediate is more stabilized (-3.6 vs.)1.3 kcal mol⁻¹). This dual kinetic and thermodynamic advantage renders path a the dominant trajectory, providing a straightforward rationale for the regioselectivity observed experimentally. In the case of 1r, however, the situation is more nuanced. The two transition states are separated by less than 1 kcal mol⁻¹, and the corresponding azirine intermediates differ only slightly in stability (path a favored by 0.9 kcal mol^{-1}). The combination of a slightly lower barrier for the path b azirine and the greater stability of the path a azirine establishes a kinetic-thermodynamic dichotomy: the path b azirine can be classified as the kinetic product, while the path a analogue represents the thermodynamic minimum. This balance provides a natural rationale for the temperature-dependent outcome: under ambient conditions both azirines may form in comparable amounts, whereas the elevated temperature equilibration shifts the distribution toward the thermodynamically preferred path a.

Synthesis of ortho-aniline

Aryl sulfoniums are powerful synthetic handles for diverse functionalization *via* cross-coupling reactions and redox chemistry.⁶⁸⁻⁷⁴ The sulfonium group can be introduced onto the aromatic ring either by exploiting existing

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prefunctionalization^{68,73} or directly via C-H functionalization, typically with para-selectivity. 69,72,74 Our protocol allows the selective installation of sulfonium groups ortho to aniline functionalities with complete regiocontrol. We envisaged that this intermediate could act as a strategic platform to enable divergent ortho-functionalization pathways, expanding the reactivity beyond nitrogen isomerization. This concept was validated as shown in (Scheme 5B). Photoredox-induced fragmentation in the presence of a chlorinating agent provided ortho-chloroaniline 6a in 69% yield.22 Similarly, blue light irradiation ($\lambda = 440$ nm) in the presence of B₂(pin)₂ afforded *ortho*borylated product 6b in 75% yield, enabling further downstream diversification through standard cross-coupling protocols.69 Furthermore, phenylphenothiazine (PTH)-mediated reduction of sulfonium 4t generated an aryl radical intermediate that was effectively intercepted by methylpyrrole and styrene to afford C-C coupled products 6c and 6d in 71% and 69% yields, respectively. Finally, the versatility of these sulfonium intermediates was showcased through a Suzuki-Miyaura cross-coupling reaction, delivering ortho-arylated aniline 6e in 69% yield.

Conclusions

We have developed a synthetic strategy for ortho-isomerization of aromatic nitrogen. This method enables the transformation of easily accessible para-substituted anilines into more challenging meta-functionalized derivatives. This protocol tolerates many functionalities often encountered in organic synthesis and has proven efficient for late-stage reconfiguration of bioactive molecules. We hope this might find application as a tool for chemical space exploration without the requirement for de novo synthesis. Furthermore, the sulfonium intermediates generated as part of the strategy can serve as a powerful linchpin for diverse transformations, including photoredox catalysis and cross-coupling. This can be used to overcome current limitations in aniline functionalization chemistry and expand the scope of accessible derivatives.

Author contributions

AR and DL conceptualized, designed, and supervised the project. GL, XY and GLB performed all the synthetic experiments. DBY performed the computational experiments. All authors analysed the results and wrote the manuscript.

Conflicts of interest

There are no conflicts to declare.

Data availability

The data that support the findings of this study are available in the supplementary information (SI) of this article. Supplementary information is available. See DOI: https://doi.org/10.1039/ d5sc05329c.

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