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Cobalt electro-catalyzed C-H acyloxylation of aromatic and vinylic amide derivatives at room temperature

Like a molecular engine, a cobalt electrocatalyst transforms ubiquitous C-H bonds into a rich harvest of valuable esters. This mild and sustainable method enables the direct formation of C-O bonds, yielding a diverse range of complex molecules for biomedical and industrial applications.

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Cobalt-electrocatalyzed C–H acyloxylation of aromatic and vinylic amide derivatives at room temperature

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9w Herein, we report a mild and efficient cobalt-catalyzed electrochemical method for the regioselective C–H acyloxylation of aromatic and vinylic amides, utilizing 8-aminoquinoline as the directing group. Notably, this protocol requires no stoichiometric oxidants and operates at room temperature in an undivided cell setup, providing sustainable access to a diverse set of *ortho*-acyloxylation products with broad functional group tolerance.

Direct C–H functionalization has emerged as a transformative strategy in organic synthesis, enabling the streamlined construction of complex molecules from readily available feedstocks.^{1,2} Among the diverse repertoire of C–H transformations, C–O bond formation, specifically through acyloxylation, remains a highly desired objective due to the widespread occurrence of ester moieties in pharmaceuticals, materials, and natural products.³ While traditional esterification methods generally require substrate pre-functionalization along with the generation of stoichiometric byproducts,^{4–16} direct C–H acyloxylation offers a powerful and atom-economical alternative. Although cobalt catalysis has shown considerable success in many realms of C–H activation, achieving efficient and selective C–O bond formation has proven challenging previously.^{4–8,17} Early work by Kochi *et al.* demonstrated the feasibility of cobalt-mediated C–O bond construction,^{18,19} yet efficient catalytic systems remained elusive.

Nevertheless, cobalt-catalyzed C–H oxygenation has significantly progressed in recent years. Zeng and co-workers described a cobalt-catalyzed cross-dehydrogenative coupling (CDC) of arenes with carboxylic acids (Scheme 1(a)), establishing a valuable precedent for accessing aryl esters through proposed aryl-Co(III) species.²⁰ Ackermann and co-workers further advanced the field with an elegant electrochemical cobalt-catalyzed C–H oxygenation protocol (Scheme 1(b)), demonstrating mild and selective oxygenation of both arenes

and alkenes under electrocatalytic conditions, which circumvented the need for stoichiometric chemical oxidants.^{21–23} Complementary to these cobalt-catalyzed approaches, copper-catalyzed or copper-mediated acyloxylation (Scheme 1(b)) have also been developed.^{9–12} The copper-based methods underscore the effectiveness of bidentate ligands in promoting site-selective C–H functionalization. Further expanding the C–O bond formation landscape, Jeganmohan and Padala reported a ruthenium-catalyzed protocol for the *ortho*-benzoxylation of benzamides.²⁴

Building on the success of 8-aminoquinoline (8-AQ) as a bidentate directing group in C–H arylation,^{25–27} we envisioned an electrochemical C–H acyloxylation strategy for aromatic and vinylic amides. The 8-AQ directing group has previously demonstrated a remarkable ability to facilitate selective C–H activation, offering promising prospects for regioselective acyloxylation. Furthermore, recent reports on electrochemical C–H acyloxylation,^{28–36} provide compelling evidence for the feasibility and potential of this approach. Several studies have successfully demonstrated electrochemical acyloxylation, highlighting the method's mild and practical nature. These precedents highlight the potential of electrochemistry to avoid harsh conditions and stoichiometric oxidants. A variety of substrates, including aromatic amides,^{28,33–35} phenols,³⁶ 2-phenylpyridines,²⁹ and 8-methylquinoline³³ have been successfully acyloxylation using electrochemical methods, showcasing the versatility of this approach.



Scheme 1 Strategies for C–H Acyloxylation. (a) Chemical methods, requiring harsh conditions. (b) Prior electrochemical methods. (c) This work: cobalt–electrocatalyzed C–H acyloxylation in an undivided cell at room temperature.

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Scheme 2 Substrate scope investigation: (a) reagents and conditions: amide (1.0 equiv.), acid (2.0 equiv.), Co(OAc)_2 (10 mol%), Na_2CO_3 (1 equiv.), DMF (4 mL), 2 mA, 24 h, rt, carbon cloth anode (1 cm^2) and platinum plate cathode (1 cm^2). Yields refer to isolated yields following column chromatography. Q = 8-quinolinyl directing group. (b) Scale-up of the present electrochemical C–H acyloxylation protocol.

(15 and 16) and CF_3 -substituted (17) amides delivered the desired products, although the electron-deficient substrate required a slightly higher catalyst loading. The protocol could also be extended to heteroaromatic amides, providing acyloxyated thiophene and pyrrole derivatives (18 and 19).

To underscore the practical utility of this method for late-stage functionalization, we applied it to complex amides derived from known pharmaceutical agents. We were pleased to find that derivatives of acetylsalicylic acid (20), the lipid-lowering drugs ciprofibrate (21), fenofibric acid (22), gemfibrozil (23 and 25), and the COPD medication roflumilast (24) were all acyloxyated in good to excellent yields (54–95%). These results demonstrate the method's potential for rapidly

generating novel analogues of biologically active molecules with minimal synthetic effort.

Gratifyingly, the protocol for C–H acyloxylation can easily be scaled up to the gram-scale, as exemplified by the reaction of cyclohexene–carboxamide 26 (Scheme 2, bottom). The reaction was performed on a 4.0 mmol (1.08 g) scale and the desired product 27 could be isolated in 71% yield.

The mechanism of the analogous metalla-electrocatalyzed transformations has been studied and reported previously.^{23,25} As depicted in Scheme 3, a catalytic cycle is proposed to comprise an irreversible, turnover-determining C–H activation to form a Co(III) -cyclometalate (C), which is subsequently oxidized to a Co(IV) species (D).^{40,41} The latter is followed by carboxylate coordination and upon C–O bond-forming reductive elimination, the product (E) is released, and the catalyst is regenerated to the resting state.

Mechanistic studies support the proposed pathway (Scheme 3). An “ON/OFF” experiment confirmed the reaction is current-dependent, ruling out a radical chain mechanism (S15). Irreversible C–H activation was confirmed by H/D scrambling experiments (S16), while UV-Vis and ^1H NMR monitoring supported the formation of a diamagnetic Co(III) species upon electrolysis (S17 and S18).

In addition, electroanalytical techniques were employed to understand the catalyst–substrate redox relationship. The state-of-the-art cyclic voltammetry (CV) were found largely uninformative in our case. Instead, differential pulse voltammetry (DPV) was employed as a method of choice, offering more sensitive detection of redox events (Scheme 3 and Fig. S3–S10). The anodic stability of carboxylates with electron donating groups is known to be poor $E_{\text{Red}} > 0.2\text{--}0.5 \text{ V vs. } E_{\text{Fc}}$, therefore model tetrabutylammonium hexafluorophosphate (TBAPF_6) was taken to investigate electrochemical behaviour of reactants. Still, oxidation of DMF itself was observed to set on at $E_{\text{Red}} > +1.2 \text{ V vs. } E_{\text{Fc}}$. Under such conditions, oxidation of Co(OAc)_2 can be seen as two weak peaks at ca. $+0.55$ and $+0.85 \text{ V}_{\text{Fc}}$, assumed to be Co(III) and Co(IV) . The poor detectability can be rationalized by the absence of specific adsorption and pronounced electrostatic migration of cationic cobalt salts in DMF away from the anode. Substrate 35 under DPV conditions is featured by two strong peaks at $+0.95$ and $+1.10 \text{ V}_{\text{Fc}}$, representing formation of radical-cation and cation species of the quinoline



Scheme 3 Plausible mechanism of cobalt electro-catalyzed C–H acyloxylation. (a) Proposed catalytic cycle. (b) Differential pulse voltammetry of reaction mixture components under model conditions.



scaffold. Interestingly, the mixing of both **35** and Co(OAc)₂ gave a rise of two new peaks, indicating a complexation process that is highly reversible, as peaks of non-coordinated ligands are still observable. This observation rationalizes the need for a low current density under preparative conditions using high-surface area carbon cloth, in order to maintain a sufficiently low potential and avoid oxidation of the carboxylate or DMF.

In conclusion, we have developed an efficient cobalt electrocatalyzed C–H acyloxylation method for aromatic and vinylic amides using 8-AQ as the directing group. This method allows for the synthesis of a wide range of acyloxyated amide compounds in good to excellent yields in an operationally simple, undivided cell setup. The electrochemical approach reduces the reliance on stoichiometric chemical oxidants, making the protocol more sustainable. This work highlights the potential of combining cobalt catalysis and electrochemistry for efficient and green C–H functionalization.

R. S.: investigation, writing – original draft. P. N.: investigation, writing – review & editing. L. M.: investigation. O. V.: conceptualization, supervision, funding acquisition, writing – review & editing. All authors have given approval to the final version.

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Conflicts of interest

There are no conflicts to declare.

Data availability

The data supporting the findings of this study are available within the article and its supplementary information (SI). Supplementary information is available. See DOI: <https://doi.org/10.1039/d5cc04394h>.

Electroanalytical data for this article, are available at Zenodo at <https://doi.org/10.5281/zenodo.16640616>.

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