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7-Substituted 2-nitro-5,6-dihydroimidazo[2,1-b][1,3]oxazines: novel antitubercular agents lead to a new preclinical candidate for visceral leishmaniasis

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Abstract

Within a backup program for the clinical investigational agent pretomanid (PA-824), scaffold hopping from delamanid inspired the discovery of a novel class of potent antitubercular agents that unexpectedly possessed notable utility against the kinetoplastid disease visceral leishmaniasis (VL). Following the identification of delamanid analogue DNDI-VL-2098 as a VL preclinical candidate, this structurally related 7-substituted 2-nitro-5,6-dihydroimidazo[2,1-b][1,3]oxazine class was further explored, seeking efficacious backup compounds with improved solubility and safety. Commencing with a biphenyl lead, bioisosteres formed by replacing one phenyl by pyridine or pyrimidine showed improved solubility and potency, whereas more hydrophilic side chains reduced VL activity. In a Leishmania donovani mouse model, two racemic phenylpyridines (71 and 93) were superior, with the former providing $>99\%$ inhibition at 12.5 mg/kg (b.i.d., orally) in the Leishmania infantum hamster model. Overall, the 7R enantiomer of 71 (79) displayed more optimal efficacy, pharmacokinetics and safety, leading to its selection as the preferred development candidate.
INTRODUCTION

The neglected tropical disease visceral leishmaniasis (VL) is the second deadliest parasitic disorder (after malaria), being most prevalent in Brazil, Sudan, Ethiopia, and the Indian subcontinent, with an estimated 350 million people at risk of infection.\(^1\) Transmitted by sand flies, the disease first manifests as an irregular fever, anaemia, leukopenia, and hepatosplenomegaly, and is usually fatal within 2 years if left untreated.\(^2\) About 300,000 new cases arise annually, almost half in children, and at least 35 countries have reported the occurrence of HIV coinfection (with up to 34% incidence), which gives a significantly higher mortality rate.\(^3,4\) Unfortunately, none of the existing VL drugs (antimonials, paromomycin, liposomal amphotericin B, or miltefosine 1; see Figure 1) is universally effective, nor free from further drawbacks, such as parenteral administration (for all except 1), toxicity, high cost, and emerging resistance.\(^5\) Furthermore, there is no available vaccine, despite renewed efforts.\(^6\) Clinical investigation of the orally active aminoquinoline sitamaquine (2) has been abandoned due to its toxicity and less satisfactory efficacy,\(^7\) and new phase II trials of the repositioned oral agent fexinidazole (3)\(^8\) for VL have also been interrupted due to patient relapses.\(^9\) With no other candidates under clinical evaluation at present, there is a desperate need for the development of more effective, safe and affordable oral remedies for VL.

We have recently reported that phenotypic screening by the Drugs for Neglected Diseases initiative (DNDi) of some nitroimidazole derivatives arising from our early studies with the TB Alliance unexpectedly led to the identification of DNDI-VL-2098 (4) as a preclinical candidate for VL.\(^10,11\) Our opening assignment with TB Alliance had been to prepare and evaluate novel nitroheterobicyclic analogues of the tuberculosis (TB) drugs delamanid (5) and pretomanid (PA-824, 6),\(^12,13\) seeking a possible third active scaffold for the construction of a backup series. However, amongst the fused 5/6 ring systems examined, only the metabolically labile 2-nitroimidazothiazines retained significant antitubercular potency.\(^14\)
returning our attention to the original oxazine class where we uncovered heterobiaryl derivatives of 6 with better efficacy (e.g., TBA-354, 7). One important consideration in the design of a superior second-generation TB candidate was the potential for cleavage of the aromatic side chain via oxidative metabolism of the 6-oxymethylene linker; therefore, several alternative linker and steric protection strategies were explored, albeit, with limited success. A final, more innovative way to address this issue was to invoke a scaffold hopping approach, by relocating aromatic side chains from the 6-position to the 7-position of the 2-nitroimidazooxazine core, with attachment via the same inverted linker (CH$_2$OR) that was present in 6-nitroimidazooxazole 5. This was equivalent to a one carbon expansion of the oxazole ring between C-2 and C-3 (Figure 2). The rationale for this design concept stemmed from initial evidence that delamanid (5) was highly stable towards metabolism, as well as from a report that 7-methyl derivatives of 6 retained excellent antitubercular potency, suggesting that such an approach merited investigation.

Serendipitously, we soon discovered that this novel “7-substituted oxazine” class not only showed considerable promise for TB (as later confirmed by others), it also displayed potent antileishmanial activity, comparable to the 6-nitroimidazooxazoles in early screening assays. Therefore, following the success with 4, this new series was similarly repositioned for VL as part of an extensive backup program, run in collaboration with DNDi. In this paper, we first highlight some critical VL hit to lead assessments on the original subset of compounds that had been prepared for TB. We then detail the findings of our lead optimisation study directed at developing backups to 4 having an improved physicochemical/pharmacological profile and better safety, which culminated in the selection of a new preclinical candidate for VL. Finally, in light of these encouraging results and the excellent activities of this novel 7-substituted 2-nitroimidazooxazine class against both TB and Chagas disease, we point to related analogues that might be worthy of further assessment for the latter applications.
CHEMISTRY

In order to rapidly access some initial examples, the racemic 7-H and 7-methyl alcohol intermediates, 13 and 20, were first sought (Scheme 1A). These could be obtained in very good overall yield (62-79%) via similar 5 step reaction sequences, starting with base catalysed alkylation of 2-bromo-4-nitroimidazole (8) using 4-bromobut-1-ene or 4-iodo-2-methylbut-1-ene (15). Dihydroxylation of the resulting alkene (OsO₄/NMO), selective TIPS protection of the primary hydroxyl group, sodium hydride-induced ring closure, and acid-catalysed desilylation completed the synthesis of both alcohols, although in the case of 20, the final two steps required gentle warming. The benzyl ether targets 14, 21-23, 25, and 27-29 were then formed by standard alkylation and Suzuki coupling methodology (Scheme 1A/B). Next, the two enantiomers of early TB lead 29 (34 and 38) were also generated via preparative chiral HPLC separation of the 7R and 7S forms of acetate derivative 30, followed by hydrolysis to the chiral alcohols (32 and 36), and elaboration as before (Scheme 1C). Here, the absolute configurations of 34 and 38 were subsequently established through an independent chiral synthesis of the 7R enantiomer (see the Supporting Information), involving alkylation of 8 with the iodide derived from 2-[(2R)-2-methyl-1,4-dioxaspiro[4.5]decan-2-yl]ethan-1-ol.

Mitsunobu coupling of alcohol 13 with appropriate phenols (Scheme 2A) successfully led to the 7-H phenyl ethers 39 and 45, together with the 4-iodo analogue 48; the latter enabled biphenyl derivatives 49 and 53, following Suzuki couplings. However, because Mitsunobu reactions were expected to be more problematic for the sterically hindered 7-methyl alcohol 20, a different approach was employed to prepare compounds 44 and 47 (Scheme 2B). Commencing with 2-chloro-4-nitroimidazole (40), alkylation with iodide 15 and buffered reaction of alkene 41 with m-CPBA provided epoxide 42 in high yield (80%). Ring opening of 42 with phenols (K₂CO₃, MEK, 82 °C) then gave alcohol intermediates that could be ring
closed to 7-substituted oxazines, as above. An attempt to combine the last two steps in one pot\textsuperscript{30} (by exposing 42 to 1.2 equivs of NaH and 4-(trifluoromethoxy)phenol in DMF at 75-86 °C) led to markedly inferior results (27% 44, with 30% 43); equally, ring opening of 42 with 4-iodophenol in DMF (K\textsubscript{2}CO\textsubscript{3}, 83 °C, 8 h) also gave a lower yield of 50 (60%) due to partial displacement of the 2-chlorine. Suzuki couplings on the ring-closed iodide 51 readily furnished biphenyl derivatives 52 and 54; terminal fluoropyridines 55 and 56 were similarly obtained from 48 and 51 through the use of a weaker base (KHCO\textsubscript{3}).

The assembly of various biaryl side chains featuring a proximal 2-pyridine ring was typically quite straightforward (Scheme 2C). Bromo-2-pyridinyl ethers (58, 60, 98, and 100) were easily formed\textsuperscript{17} via sodium hydride-catalysed S\textsubscript{N}Ar reactions of alcohols 13 and 20 with the fluoropyridines 57 and 97, and Suzuki couplings then supplied the phenylpyridine or bipyridine targets in generally high yields (62-98%). Nevertheless, it proved very challenging to prepare analogues 105 and 106 having a 2-pyridine terminal ring. One pot treatment of bromides 58 and 60 with bis(pinacolato)digiboron (to generate the boronate ester), followed by in situ Suzuki coupling\textsuperscript{31} with 2-bromo-5-fluoropyridine, gave 105 and 106 in poor yields (8-15%). However, a copper(I)-facilitated Suzuki approach,\textsuperscript{32} designed to mitigate facile protodeboronation of the required 2-pyridyl boronate, was not any better (15% yield of 106).

For more efficient synthesis of 7-H biaryl analogues having a proximal 3-pyridine ring, an epoxide-opening strategy (Scheme 3A) was preferred over the Mitsunobu route described above. Epoxide 67 was obtained in 72% optimised yield from 2-chloro-4-nitroimidazole (40), via alkene 66; in this case, the slow epoxidation step was best achieved under non-buffered conditions at higher concentration (with initial cooling). Ring opening of 67 with 6-bromopyridin-3-ol (68) (K\textsubscript{2}CO\textsubscript{3}, MEK, 81-82 °C) gave mainly alcohol 69 (51% using 2 equiv for 35 h, or 57% from 4 equiv and 14 h), together with small amounts of the oxazine 70 (6-12%). Ring closure of purified 69 (NaH, DMF, 0-20 °C) then gave additional 70 in excellent
yield (91%). Comparable results were obtained for scale-up of 39 from 67 (62%), as well as for reaction of epoxide 42 with pyridinol 68 and ring closure, leading to oxazine 89 (Scheme 3D). As expected, bromides 70 and 89 both proved to be excellent substrates for Suzuki couplings to access the remaining racemic phenylpyridine and bipyridine targets.

By alkylation 2-chloro-4-nitroimidazole (40) with (4R)-4-(2-iodoethyl)-2,2-dimethyl-1,3-dioxolane33 (72) (or its optical isomer, 8033), it was possible to transform the above racemic route into a viable chiral synthesis for delivery of both enantiomers of two advanced leads, 71 and 93 (Scheme 3B/C). The two chiral acetal products 73 and 81 were readily converted into the R and S enantiomers of epoxide 67 (76 and 84) by successive hydrolysis (to diols 74 and 82), tosylation at the primary hydroxyl, and internal substitution to form the oxirane ring (DBU). These chiral epoxides were then elaborated to the final products by reaction with 68, ring closure, and Suzuki coupling, as previously described.

The preparation of biaryl congeners 123, 126, 129, 131-133, and 139 in which the first ring was pyridazine, pyrazine, or pyrimidine followed similar procedures to those developed for the pyridine analogues. Thus, sodium hydride-induced S_N_Ar reactions of alcohols 13 and 20 with haloheterocycles 121, 124, and 127 readily provided the bromoheteroaryl ether intermediates needed for final step Suzuki couplings (Scheme 4A). However, the remaining arylpyrimidine target (139) required prior assembly of the biaryl side chain. Initial protection of 2-chloropyrimidin-5-ol (134) as an ethoxymethyl ether derivative (135), followed by Suzuki coupling and acidic deprotection supplied arylpyrimidinol 137 in excellent yield (83% from 134; Scheme 4B). Reaction of 137 with epoxide 67 produced a 5:2 mixture of the alcohol 138 and the ring closed oxazine (139); treatment of 138 with sodium hydride then completed this synthesis.

Scheme 5 outlines the methods used to obtain compounds 142, 144, 147, 149, 152, 154, 157, 159-161, 170, and 178, whose side chains contained either piperazine or piperidine
linked to an aryl group. Ring opening of epoxides 67 and 42 with the known or commercial amines 140, 145, 150, and 155 easily generated the expected β-amino alcohols in high yield (Scheme 5A/B). These alcohols could be ring closed to the final products with sodium hydride upon mild heating; albeit, yields for the 7-methyl analogues were generally significantly lower, in part, due to greater purification difficulties. Chloroformylation of alcohols 13 and 20 (triphosgene/Et3N) and in situ reaction with arylpiperazine 140 also led to the O-carbamates 160 and 161 in only modest yield (33-35%; Scheme 5C) on account of similar purification issues; the isolation of alkyl chloride and diethyl carbamate derivatives under the same reaction conditions has been reported recently.35 Lastly, synthesis of the two O-linked arylpiperidines, 170 and 178, was eventually achieved in each case via a lengthy 7 step route (Scheme 5D), after the failure of a more direct plan (ring opening of epoxide 67 with piperidinol 163 in the presence of erbium triflate37). Here, piperidinol 163 was first sourced in three steps, by Buchwald amination of 1-bromo-4-fluorobenzene with 1,4-dioxa-8-azaspiro[4.5]decane, ketal hydrolysis, and reduction (NaBH4). Reaction of epoxides 162 and 171 with 163 (NaH, DMF, 70 °C) and TBS protection of the liberated hydroxyls provided the desired ethers 165 and 173 in good yield (47-68% overall). Successive benzyl removal (via hydrogenolysis), iodination, and alkylation of 2-chloro-4-nitroimidazole (40) then gave the TBS-protected adducts, 168 and 176, which were readily desilylated (TBAF) and ring closed to furnish the final targets.

RESULTS AND DISCUSSION
The structures and in vitro antiparasitic and antitubercular potencies of 75 novel 7-substituted 2-nitroimidazooxazine derivatives prepared in two collaborative projects are provided in Tables 1 and 2. While compounds 14, 21-23, 25, 27-29, 34, 38, 39, 44, 45, 47, 49, and 52-54 were initially designed and evaluated for TB, for clarity purposes, we will focus the discussion first on the more recent VL work with DNDi. Here, new synthesis was directed at
the optimisation of solubility, efficacy, and safety, primarily through the incorporation of heterocycles to reduce compound lipophilicity\textsuperscript{11} (estimated by CLogP data derived from ACD LogP/LogD software, version 12.0; Advanced Chemistry Development Inc., Toronto, Canada). Kinetic aqueous solubility measurements were conducted on dry powder forms of particular examples that were being considered for further evaluation. Target compounds were initially screened only once against \textit{Leishmania donovani} (\textit{L. don}) using a mouse macrophage-based luciferase assay conducted at the Central Drug Research Institute (CDRI, India).\textsuperscript{10} Nevertheless, in order to gain a clearer understanding of the SAR (in view of some unexpected \textit{in vivo} outcomes), the entire set was finally re-evaluated at the University of Antwerp (LMPH) in replicate assays against three protozoan parasites: \textit{L. infantum} (\textit{L. inf}), \textit{T. cruzi}, and \textit{T. brucei}.\textsuperscript{40} Assessments of cytotoxicity were concurrently conducted on both human lung fibroblasts (MRC-5 cells; the host for \textit{T. cruzi}) and primary peritoneal mouse macrophages (the host for \textit{L. inf}), which revealed that the compounds were generally nontoxic (MRC-5 IC\textsubscript{50}s >55 \textmu M except for 117: IC\textsubscript{50} 35 \textmu M), as confirmed for TB (VERO assay\textsuperscript{41} IC\textsubscript{50}s >128 \textmu M for 71 of 72 compounds).

1. Early hit to lead assessments for VL

Through an agreement between TB Alliance and DND\textit{i}, 58 nitroimidazole derivatives were screened against \textit{L. don} at the Swiss Tropical Institute. All five 7-substituted oxazines (including 22, 23, and 28) demonstrated excellent potencies in the \textit{in vitro} mouse macrophage assay (IC\textsubscript{50}s 0.065-0.17 \textmu M, similar to racemic 4), prompting the inclusion of 28 alongside \textit{rac-4} (and another oxazole\textsuperscript{11}) in a proof-of-concept \textit{in vivo} assessment at the London School of Hygiene and Tropical Medicine (LSHTM). However, the level of activity observed for 28 in this \textit{L. don} mouse model (49% inhibition at 50 mg/kg, dosing po daily for 5 d; Table 3) was not notable in comparison to the results for \textit{rac-4} (99% at 6.25 mg/kg),\textsuperscript{11} suggesting that further optimisation of the side chain would be necessary. Indeed, while 28 showed good
stability on exposure to mouse liver microsomes (MLM: 75% remaining after 1 h, Table 3) and gave a mouse pharmacokinetic (PK) profile comparable to rac-4 (Table 4 and Supporting Information, Figures S1 and S2), it was very hydrophobic (CLogP 5.14) and displayed poor solubility (~58 ng/mL at pH 7, Table 3; 62-fold lower than for rac-4). Such compounds typically exhibit high levels of plasma protein binding (PPB), which can limit efficacy. We have also observed that increased linker flexibility can be detrimental to in vivo activity.

While these mouse studies were being conducted, a further thirty 7-substituted oxazine derivatives were screened against L. don in the luciferase assay at CDRI. Based on the single IC₅₀ data obtained for 14, 21-23, 25, 27-29, 34, 38, 39, 44, 45, 47, 49, and 52-54 (Table 1), several preliminary SAR conclusions were drawn: (1) the 7-H series was generally 5- to 10-fold more potent than the 7-methyl series; (2) 4-trifluoromethoxy and 4-benzyloxy substituents (forms A and C) provided equivalent potency; (3) for biaryl analogues (forms B and D), 4-fluoro was preferred over 4-trifluoromethoxy as the final ring substituent (as observed in the 6-nitroimidazoazoxazole series); (4) a shorter linker (forms C and D) was preferred in the majority of cases. Thus, the most active analogues appeared to be 14, 22, 25, 39, 45, 49, and 53 (IC₅₀s 0.01-0.06 µM, similar to 4). However, benzyl ether 14 did not display suitable metabolic stability (10% parent left after 1 h with MLM; Table 3), while evidence from the 6-substituted oxazine series for the more rapid metabolism of benzyloxybenzyl analogues dissuaded further testing of 22 and 45. Moreover, following the disappointing results with 28, we were not optimistic of good in vivo efficacy with close analogue 25, despite its improved potency. Therefore, we elected to initially investigate 39, 49 and 53 as potential leads, together with two counterparts from the 7-methyl series, 44 and 54, to enable a head-to-head comparison.

The selected compounds were advanced to parallel mouse PK profiling and efficacy studies in the mouse VL model. Encouragingly, both phenyl ether 44 (the direct analogue of rac-4)
and biphenyl congener 49 showed excellent efficacy at 25 mg/kg (99.9-100% inhibition; Table 3 and Figure 3b). Surprisingly, the more potent 7-H counterpart of 44 (39) was slightly less active in this assay (87% inhibition), mimicking findings for the 2-H equivalent of rac-4.11 Moreover, the biphenyl derivatives of 39 and 44 (53 and 54) were also less impressive than 49 (65% and 30% inhibition, respectively). However, while these latter results appeared to track well with the single determination L. don data, they did not seem to line up with the almost equivalent mean potencies vs L. inf (Table 1). The findings also appeared to conflict with the kinetic solubility and microsomal stability data (Table 3), where 49 was as poorly soluble as 28 (55 vs 58 ng/mL) but the more stable analogue 54 (85 vs 75% in MLM) was 45-fold more soluble than 28 (2.6 µg/mL). Solubility is discussed further in the next section.

Analysis of the mouse PK data (Table 4) provided greater insight, revealing that 39 had a 4-fold higher rate of clearance than its 7-methyl derivative 44 (48 vs 12 mL/min/kg), resulting in a short half-life (1.1 h vs 2.8 h for 44) and quite poor oral exposure (see the Supporting Information, Figure S1). Interestingly, with iv administration, the PK profiles for 44 and rac-4 were fairly similar, but 44 did not perform as well under oral dosing, with rather modest absorption (C_max 1.4 µg/mL, 3-fold less than for rac-4) contributing to reduced exposure and moderate oral bioavailability (35% vs 79%). The oral parameters for compound 54 were also mediocre (poor C_max of 0.79 µg/mL and low oral bioavailability of 17% offsetting its lengthy 27 h half-life), potentially explaining its inferior efficacy in the mouse VL model. However, the findings for 49 and 53 were more puzzling, with the less efficacious 53 demonstrating greater oral exposure (see the Supporting Information, Figure S1), superior oral bioavailability (100% vs 11% for 49), and an extended half-life (17 h vs 6.7 h for 49). Nevertheless, like 28, 53 was particularly hydrophobic (CLogP 5.03), so high PPB may be a major issue limiting its efficacy.42 We have previously observed that PK data is not always correctly predictive of in vivo efficacy ranking.43
These promising results prompted further appraisal of the most active compounds, 44 and 49. In the mouse VL model, 44 provided robust dose-response data (Table 3), giving an ED$_{50}$ value of 4.2 mg/kg (cf. 3.0 mg/kg for rac-4$^{11}$). Unfortunately, additional studies of 49 in this model (using material prepared elsewhere) were unable to replicate the original result; we postulate that this discrepancy may be due in part to the extremely poor aqueous solubility and inadequate oral bioavailability of this compound, rendering oral suspension formulations particularly sensitive to particle size. Nevertheless, the optimal in vivo assay for assessing the efficacy of test compounds against VL is the chronic infection hamster model, which better reproduces the clinical pathology of human disease.$^{44}$ In the L. don hamster model at CDRI, leads 44 and 49 were almost equally effective at 50 mg/kg, with 5 days of oral dosing leading to 53% and 51% inhibition of parasite infection in the spleen, whereas rac-4 gave 86% inhibition under the same dose regimen.$^{11}$

A significant factor in the suboptimal activity of 44 in the hamster model was thought to be its exceptionally rapid metabolism in this species, as revealed by the hamster microsomal stability data (only 16% remaining after 0.5 h vs 49% for rac-4$^{11}$). Therefore, 44 was later reassessed in the L. inf early curative hamster model at LMPH, comparing a twice-daily dose regimen (25 mg/kg b.i.d.) with a once-daily dose of 50 mg/kg. The results (Table 5) slightly favoured the twice-daily regimen for all 3 target organs; hence this protocol became standard for most test compounds. However, unlike 4, 44 was not curative at this dose level. Another liability with 44 was its greater inhibition of the hERG channel (IC$_{50}$ 3.8 µM vs 10.5 µM for 4), with IC$_{50}$ values in excess of 10 µM required to minimise QT prolongation risk.$^{45}$ Hence, as lead compounds for VL, 44 and 49 fulfilled many suggested criteria,$^{46}$ but still had key deficiencies, reflecting their origin as screening hits in a scarcely studied new class.

2. SAR of 7-substituted 2-nitroimidazooxazines for VL
Following the identification of 4 as a preferred drug candidate and the discovery of 44 and 49 as unoptimised new leads, a backup program was launched to develop second generation agents for VL having better solubility, PK-PD and safety profile. Due to the inferior profile of 44 in comparison to 4 in several key areas, we elected to centre our synthetic strategy mainly on bicyclic side chains, employing heterocycles to modulate lipophilicity and solubility. Six-membered ring nitrogen-containing variants were preferred, due to their greater metabolic stability; ortho-substitution of aryl groups and meta-linkage of rings were also investigated as additional options to increase solubility. Recognising that few orally active registered drugs have solubility values below 1 µM at pH 7.4 (the pH of blood), we aspired to achieve at least 10-fold higher than this for the best compounds. We also aimed to exploit the low pH of gastric fluid (~1 to 2) to improve dissolution and oral absorption of analogues containing pyridine and other bases. Hence, we set a minimum solubility requirement for the preferred final candidate of being non-inferior to delamanid (5) (0.31 µg/mL at pH 7 and 116 µg/mL at pH 1), an approved TB drug in Europe and Japan.

Based on the wider in vitro screening results, it was apparent that the 7-substituted oxazines could not be used for African trypanosomiasis (T. brucei IC50s mostly >64 µM, none <1 µM; see the Supporting Information, Tables S1 and S2). However, unlike the 6-nitroimidazooxazoles, this new oxazine class generally showed interesting potencies against T. cruzi (IC50s 0.03-1 µM), suggesting the possibility of dual utility to treat both VL and Chagas disease. Further analysis of data for the 65 racemic compounds tested indicated a modest trend for the best VL leads to have high potencies against T. cruzi (see the Supporting Information, Figure S4). Hence, for simplicity, we will focus this part of the SAR discussion entirely on the intended primary application (VL), emphasising the key L. inf results.

To begin with, a reanalysis of the initial dataset (up to and including 54; Table 1) confirmed weak trends on L. inf for the 7-H analogues to be more potent and a shorter linker
length to be preferred (e.g., 39: IC_{50} 0.047 µM), but there was no consistent preference for 4-fluoro as the terminal ring substituent. Nevertheless, in view of the better in vivo efficacy of 49 and similarly substituted nitroimidazooxazoles, we retained this latter design element in the majority of cases. Thus, compounds 55 and 56 first investigated the effect of replacing the second phenyl ring of 49 by pyridine (ΔCLogP -1.2 units). Pleasingly, this led to a 2- to 6-fold potency increase, with 55 (IC_{50} 0.083 µM) also being 6.5-fold more soluble than 49 (0.36 vs 0.055 µg/mL, Table 3). Exchange of the first phenyl ring by 2-pyridine (59 and 61; ΔCLogP -0.5 units) resulted in even better activity (59: IC_{50} 0.050 µM), and in this case solubility values were ~20-fold higher at low pH (2.8-13 µg/mL; caled pK_a 2.83), although still rather modest. Therefore, we examined the addition of an ortho fluorine in the phenyl ring (62 and 63), in an attempt to break up the planarity. However, while this change was well tolerated, there was no improvement in solubility and microsomal stability was reduced (19% vs 43% in MLM for 62 vs 59, Table 3). In an alternative approach, we tried meta-linkage of the rings (99 and 101-103), but although the activity was generally acceptable, this led to inferior solubility (99: 27 ng/mL).

Turning instead to 3-pyridine as a first ring, potency was maximised by 2,4-difluorophenyl substitution (91: IC_{50} 0.030 µM), although the 4-fluoro and 4-trifluoromethoxy (7-H) analogues (71 and 93) were also useful (IC_{50}s 0.093 and 0.12 µM, respectively). Importantly, aqueous solubility values were up to 13-fold better than for 49 at neutral pH (91: 0.72 µg/mL) and 3 orders of magnitude better at low pH (91: 221 µg/mL). This was consistent with a greater lipophilicity reduction for the 3-pyridine (ΔCLogP -1.1 units) and a slightly higher basicity (e.g., 71: caled pK_a 3.76). Final assessment of the enantiomers of two examples, 71 and 93, identified the R forms (79 and 94) as slightly preferred for both potency and microsomal stability (particularly in the case of 79).
In view of the promising results with phenylpyridines, we elected to investigate the more hydrophilic bipyridines (105-120). Most of these showed interesting potencies in the initial L. don screen and further assessments had identified 108, 112, and 113 as being of potential interest, based on their improved solubilities in comparison to 49 (2.3-4.5 vs 0.055 µg/mL). However, on retesting, almost all of the 7-H compounds displayed markedly inferior utility against L. inf (IC50s 2.5 to >64 µM) while the 7-methyl bipyridines retained moderate potencies (IC50s 0.20-1.1 µM). It is intriguing to speculate that this might indicate a “minimum lipophilicity” requirement for activity (e.g., CLogP ~2.5) because a similar pattern was noted for all of the more hydrophilic analogues (see analysis of racemic 7-H dataset, Figure 4). Another strategy for heterobiaryl analogues of 49 was to exchange the first phenyl ring with pyridazine, pyrazine, or pyrimidine (123, 126, 129, 131-133, and 139). Of these, pyrimidine (129, 131, and 139) provided the best activity (IC50s 0.21-0.29 µM), although combining this with a pyridine ring (132, 133) led to a dramatic loss of potency (21- to >220-fold). Overall, pyrimidine 129 had the best aqueous solubility (1.8 µg/mL; 33-fold better than 49), along with acceptable metabolic stability.

More structurally diverse targets (142, 144, 147, 149, 152, 154, 157, 159-161, 170, and 178; Table 2) were designed on the premise that arylated cyclic amines can be effective bioisosteres for biphenyls, thus facilitating substantial boosts in solubility. Several side chains of this type have previously shown promise for TB and/or VL, including in the recent development of antileishmanial aminopyrazole ureas. It was initially encouraging to see four examples (arylpiperazine 142, aryloxypiperidines 152 and 154, and arylpiperazine carbamate 161) exhibiting reasonable potencies in the L. don screen (IC50s 0.19-0.45 µM), with 142 and 152 displaying a markedly better solubility profile than 49 (10-49 µg/mL at pH 7, 15-21 mg/mL at low pH). However, the L. inf data did not fully match the L. don results; instead, the 7-methyl analogues were clearly favoured over the 7-H compounds (by 3- to 7-
fold) and the more lipophilic piperidines 149 and 154 were superior (IC$_{50}$s 0.32 µM). The hydrophilic benzoylpiperazines 157 and 159 were particularly poor in both assays, as was the 7-H arylpiperazine carbamate 160. In view of these SAR findings, two O-linked phenylpiperidines (170 and 178) were subsequently designed as structurally closer mimetics for the O-linked biphenyl 49. Gratifyingly, 170 demonstrated both good potency (IC$_{50}$ 0.24 µM) and much better solubility than 49 (6.1 µg/mL at pH 7, 34 mg/mL at pH 1); albeit, the microsomal stability of this compound (17-33% in MLM and HLM) was regarded as quite marginal.

Integration of the initial *L. don* data with the kinetic solubility and microsomal stability results led to the selection of 9 new racemic analogues of 49 for testing in the *L. don* mouse model (dosing at 50 mg/kg for 5 d; Table 3 and Figure 3a). Encouragingly, a first experiment on 3-pyridine derivative 71 (4-FPh) yielded a 100% parasite clearance from the liver in all mice. Following this, 4-trifluoromethoxy congener 93 was found to be equally efficacious (99.5%), whereas the 2,4-difluoro example 91 was slightly less effective (91% inhibition). However, the less potent 7-methyl derivative of 71 (90) and the more potent 2-pyridine analogue 59 were only moderately active (41% and 67%, respectively); it is possible that the higher crystallinity (larger particle size) of 59 may have contributed to poor oral bioavailability.$^{42,48}$ Two more soluble heterobiaryl analogues, bipyridine 112 and phenylpyrimidine 129, also displayed lower efficacy (44% and 85% inhibition); oral PK data on 112 (Table 4 and Supporting Information, Figure S2) were comparable to those of 71 so this may be a potency issue (as suggested by the disparate *L. inf* and *L. don* IC$_{50}$s of >64 vs 0.09 µM). Finally, the inferior *in vivo* outcomes for two potential bioisosteres of 49, phenylpiperazine 142 (55%) and O-linked phenylpiperidine 170 (45%), may be attributed to either weaker *in vitro* activity on retesting (for 142: *L. inf* IC$_{50}$ 2.3 µM) or more rapid metabolism (for 170), as indicated above. No adverse effects were noted in any of the in vivo
experiments and the percentage weight changes for the mice were well within normal thresholds (see the Supporting Information, Table S4).

Dose-response appraisal of 71 in this mouse model provided an ED$_{50}$ value of 5.1 mg/kg (cf. 4.2 mg/kg for 44) whereas the trifluoromethoxy analogue 93 was unexpectedly ~3-fold better (50% at 1.56 mg/kg; Table 3). Therefore, the enantiomers of both 71 and 93 were assessed and in each case the $R$ form (79 and 94) gave higher efficacy, with 94 (84% at 1.56 mg/kg) outperforming the preclinical candidate 4 (49%). Meanwhile, 71 was further evaluated in the *L. inf* hamster model at LMPH. A dose regimen of 25 or 12.5 mg/kg b.i.d. for 5 days enabled parasite burden reductions exceeding 99% for all 3 target organs (Table 5 and Figure 5), similar to 4 at 25 mg/kg once daily (q.d.). However, 71 was slightly less effective than 4 when given via the 12.5 mg/kg q.d. schedule. A final head-to-head comparison of the enantiomers of 71 confirmed 79 as the preferred stereoisomer, based on its superior efficacy at two dose levels. This result was also supported by favourable PK data e.g., a higher exposure than 87 in hamsters, with an acceptable half-life (3.1 h) and good oral bioavailability (34%) in the rat (Table 4 and Supporting Information, Figure S3). Although 94 was not tested in the hamster model, it is thought that 79 may still offer some advantages as a lead candidate e.g., lower lipophilicity (by ~1 log unit) and reduced molecular weight (this could lessen PPB and improve safety),$^{42}$ slightly better solubility (a calculated pK$_a$ value of 3.76 vs 3.42 for 94), and a physical form more suitable for oral administration.

In line with our initial objective to develop improved drug candidates as backups to 4, it was pertinent to examine some additional properties of 79 (Table 6). Compared to 4, 79 had a very similar molecular weight (370 vs 359 Da) and provided thermodynamic solubility values that were clearly superior to 4 as the pH approached the measured pK$_a$ value of 3.95. It also had a lower experimental LogD value (2.45 vs 3.10), close to that of pretomanid (6)$^{18}$ Furthermore, like 4,$^{54}$ 79 displayed high permeability (without being a substrate for P-gp
mediated efflux), although it did show a slightly greater binding to human plasma proteins (96.5 vs 93.9%). In terms of safety, 79 gave a low inhibition of hERG (IC$_{50}$ >30 µM), did not inhibit CYP3A4 (IC$_{50}$ >100 µM), and was not mutagenic (Ames test). These characteristics broadly match the suggested criteria for clinical development of a new entity for VL, so following a belated concern with 4, 79 has now been selected as a new preclinical candidate.

3. SAR of 7-substituted 2-nitroimidazooxazines for TB

Although the primary goal of our work with DNDi was a new drug for VL, the series was originally designed and exemplified for TB, seeking a novel second-generation backup to 6 (now in phase II/III clinical trials$^{13}$). Hence, the antitubercular activities of the 7-substituted oxazine derivatives have remained an aspect of significant ongoing interest. The work began with the preparation of an exploratory set of four compounds (14, 22, 39, and 45; Table 1). Growth inhibitory effects against *Mycobacterium tuberculosis* (M. *tb*, strain H37Rv) were studied under both aerobic (replicating) and hypoxic (non-replicating) conditions (MABA$^{41}$ and LORA$^{56}$ assays, respectively), in recognition of the varying modes of action of 6 under each state,$^{57}$ and the suggestion that optimising for hypoxic activity may lead to agents with better sterilizing ability against persistent bacteria;$^{56}$ recorded MIC data (for at least 90% inhibition) represent the mean of 2-5 independent measurements. Compared with racemic 6 (MICs of 1.1 and 4.4 µM in MABA and LORA, respectively),$^{14}$ compounds 14 and 22 showed potencies of similar magnitude, stimulating further interest and the synthesis of more than 30 new analogues, including 21, 23, 25, 27-29, 44, 47, 49, and 52-54 (Table 1). These featured two design elements that had proven most advantageous for enhancing *in vivo* efficacy in early studies of 4 and 6, namely, biaryl extension, and methylation adjacent to the ring oxygen.$^{11,30,58}$

From this larger dataset, it was observed that 7-methyl congeners (e.g., 21, 23, 44, and 47) were generally slightly more effective than 7-H counterparts, and that biphenyl side chains
(e.g., 25, 27-29, 49, and 52-54) provided roughly an order of magnitude further improvement in MABA MIC values (whereas LORA data were less responsive to these changes). The phenylbenzyl derivative 29 was earmarked as a potential early lead, based on its better MIC profile (0.093 and 1.4 µM in MABA and LORA) and good stability toward MLM and HLM (77-85% parent remaining after a 1 h exposure, Table 3). Thus, for preliminary proof of principle, the enantiomers of 29 (34 and 38) were prepared and assessed in the acute TB infection mouse model alongside 6, dosing orally at 100 mg/kg daily (5 days/week) for 3 weeks. In this experiment, the R enantiomer 34 displayed equivalent efficacy to 6, but the S form 38 was 5-fold less active (Figure 6), in accordance with its weaker potency and MLM stability data. Nevertheless, the very high lipophilicity of 34 (CLogP 5.52) and its inferior PK profile in comparison to the shorter linked analogue 53 (Table 4) imply that far better in vivo effects might be achievable with optimised compounds (as shown for VL; cf., 94 vs 28).

The early preference for 7-methyl substitution was not a consistent pattern across heterobiaryl derivatives, where the most potent examples, notably phenylpyridines 59, 64, 93 and 94, as well as phenylpyrimidine 129 (MABA MICs 0.02-0.04 µM) were 7-H compounds. As found for the 6-substituted series,16 bipyridine and other heterobiaryl analogues were generally less impressive (except the 4-CF3 congener 111), particularly when the rings were meta-linked (corresponding phenylpyridines 99 and 101-103 also displayed markedly reduced activity). Finally, arylated cyclic amine bioisosteres (Table 2) showed moderate to weak potencies overall, with the hydrophilic benzoylpiperazines 157 and 159 being especially poor. For side chains A-C, 7-methyl compounds exhibited an order of magnitude better aerobic activity than their 7-H counterparts, although LORA results were disappointing for these and the related O-linked phenylpiperidines (170 and 178). Nevertheless, it was recognised that most of these new 7-substituted oxazines possessed a 4-fluoro substituted terminal ring, whereas more lipophilic 4-trifluoromethoxyphenyl (or 4-CF3pyridine) termini
were favoured for TB\textsuperscript{16-18,43,58} (as seen for phenylpyridines 93-95 vs 71, 79, and 87). Therefore, a few additional examples of the latter type (189-194 and 198: Supporting Information, Table S3) were also made and evaluated. Here, 191 and 198 (4-OCF\textsubscript{3}) were 10- to 16-fold more effective than 123 and 139 (4-F) in both TB assays (192-194 were also 2- to 8-fold better than 126, 129, and 131 in MABA), confirming this same SAR pattern. Overall, taking into account potency\textsuperscript{46} (needing to be superior to 5\textsuperscript{11}), solubility and metabolism effects, it is considered that phenylpyridine 94 is the most promising lead for TB.

CONCLUSIONS

Through a scaffold hopping design strategy, 7-substituted 2-nitroimidazooxazines were identified as a third, highly active nitroimidazole-based class of antitubercular agents, having a remarkable similarity in properties to 2-substituted 6-nitroimidazooxazoles. Phenotypic screening of some unoptimised early examples against kinetoplastid diseases led to the detection of two compounds (44 and 49) having significant efficacy against VL in mouse and hamster models, although these proved to be inferior to preclinical lead 4 as potential drug candidates. Based on our experiences in the original two classes (with 4 and 6), we then sought to develop more suitable second-generation agents for VL by systematically exploring heterocyclic side chain variants of biphenyl lead 49. Replacement of one or both phenyl rings by pyridine (or pyrimidine etc.) enabled large modulations in lipophilicity (ΔCLogP -0.5 to -2.7 units), with concomitant improvements in aqueous solubility (2- to 71-fold at pH 7 and ~4000-fold at pH 1 for phenyl-3-pyridines). In a complementary bioisostere approach, the incorporation of piperazine or piperidine for the first ring produced even greater solubility enhancements (e.g., 170: 34 mg/mL at low pH). However, more subtle strategies (viz. ortho-substitution of aryl groups and meta-linkage of aryl rings) proved less beneficial overall.

Interestingly, potency against \textit{L. inf} appeared to show some dependence on lipophilicity, with the most effective 7-H compounds falling in a CLogP range of 2.9-4.0, and compounds
of CLogP <2.5 having weak or negligible activity. This was aptly demonstrated by the improved potency of fluorinated phenylpyridines (5- to 16-fold over 49), in which the pyridine could be either terminal or proximal to the linker, whereas the combination of two pyridine rings was strongly deactivating, except in the presence of a 7-methyl substituent. Phenylpyrimidine and phenylpiperidine were the only other side chains to provide substantial activity in this assay. It has recently been shown\textsuperscript{59} that a novel nitroreductase (NTR2) in *Leishmania* is responsible for the activation of nitroimidazooxazoles such as 4; therefore, differential nitroreductase binding may be a major factor behind the *in vitro* SARs for both VL and TB.\textsuperscript{57} Evaluation of a representative set of nine racemic compounds in the VL mouse model pinpointed phenylpyridines 71 and 93 as the most efficacious, with 93 being as impressive as 4 (50% inhibition at 1.56 mg/kg). In the chronic infection *L. inf* hamster model, 71 (at 12.5 mg/kg b.i.d.) achieved >99% reductions in parasite burden for all 3 target organs. Subsequent synthesis and assessment of the enantiomers of both leads identified the *R* forms (79 and 94) as superior, and in the case of 79 this outcome was reinforced by excellent results in the *L. inf* hamster model and favourable PK data in the hamster and rat. Importantly, 79 (DNDI-0690) also provided a better safety profile than 4 and has now been selected as a new preclinical candidate for VL.

Finally, as found for the nitroimidazooxazole series,\textsuperscript{11} it was intriguing to note that some of the best VL leads (e.g., 59, 79, 93, 94, and 129) showed highly potent *in vitro* effects against TB, with both *R* enantiomers and 4-trifluoromethoxy analogues most preferred, pointing to 94 (MABA MIC 0.024 µM) as the favoured TB candidate for further evaluation. The *S* form of 93 (95) also displayed interesting activity against *T. cruzi* (IC\textsubscript{50} 0.13 µM), indicating a possible application for treating Chagas disease. This investigation has therefore revealed that the 7-substituted 2-nitroimidazooxazine class has exciting potential to treat up to 3 neglected diseases and can deliver drug candidates that are worthy of examination in ongoing studies.
EXPERIMENTAL SECTION

Combustion analyses were performed by the Campbell Microanalytical Laboratory, University of Otago, Dunedin, New Zealand. Melting points were determined using an Electrothermal IA9100 melting point apparatus, and are as read. NMR spectra were measured on a Bruker Avance 400 spectrometer at 400 MHz for $^1$H and 100 MHz for $^{13}$C and are referenced to Me$_4$Si or solvent resonances. Chemical shifts and coupling constants are recorded in units of ppm and hertz, respectively. High-resolution fast atom bombardment (HRFABMS) mass spectra were determined on a VG-70SE mass spectrometer at nominal 5000 resolution. High-resolution electrospray ionisation (HRESIMS) mass spectra were determined on a Bruker micrOTOF-Q II mass spectrometer. Low-resolution atmospheric pressure chemical ionisation (APCI) mass spectra were obtained for organic solutions using a ThermoFinnigan Surveyor MSQ mass spectrometer, connected to a Gilson autosampler. Optical rotations were measured on a Schmidt + Haensch Polartronic NH8 polarimeter. Column chromatography was performed on silica gel (Merck 230-400 mesh). Thin-layer chromatography was carried out on aluminium-backed silica gel plates (Merck 60 F$_{254}$), with visualization of components by UV light (254 nm), I$_2$, or KMnO$_4$ staining. Tested compounds (including batches screened in vivo) were $\geq$95% pure, as determined by combustion analysis (results within 0.4% of theoretical values) and/or by HPLC conducted on an Agilent 1100 system, using a 150 mm x 3.2 mm Altima 5 µm reversed phase C18 column with diode array detection. Preparative reversed phase HPLC was performed using a Gilson Unipoint system (322-H pump, 156 UV/vis detector) with 250 mm x 21 mm Synergi Max-RP 4 µm C12 or Zorbax 7 µm SB-C18 columns. Finally, preparative chiral HPLC was carried out on similar equipment by employing a 250 mm x 20 mm CHIRALPAK IA 5 µm semi-preparative column, while chiral purity was assessed using 250 mm x 4.6 mm CHIRALPAK IA or CHIRALPAK AS-H 5 µm analytical columns.
Compounds of Table 1. The following section details the syntheses of compounds 14, 25, 34, 44, 55, 59, and 79 of Table 1, via representative procedures and key intermediates, as described in Schemes 1-3. For the syntheses of all of the other compounds in Table 1, please refer to the Supporting Information.

Synthesis of 14 (Scheme 1A):

Procedure A: 2-Bromo-1-(but-3-en-1-yl)-4-nitro-1H-imidazole (9). A mixture of 2-bromo-4-nitro-1H-imidazole (8) (2.50 g, 13.0 mmol), 4-bromobut-1-ene (2.00 mL, 19.7 mmol), and powdered K$_2$CO$_3$ (5.39 g, 39.0 mmol) in anhydrous DMF (25 mL) under N$_2$ was stirred at 73 °C for 4.5 h. The resulting cooled mixture was added to ice/aqueous NaHCO$_3$ (200 mL) and extracted with EtOAc (4 x 200 mL). The extracts were washed with water (200 mL) and then evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-10% EtOAc/petroleum ether first gave foreruns, and then further elution with 20% EtOAc/petroleum ether gave 9 (2.96 g, 92%) as a pale yellow oil that solidified on cooling: mp 28-30 °C; $^1$H NMR (CDCl$_3$) $\delta$ 7.77 (s, 1 H), 5.75 (ddt, $J$ = 17.1, 10.2, 6.9 Hz, 1 H), 5.18 (dq, $J$ = 10.2, 1.1 Hz, 1 H), 5.12 (dq, $J$ = 17.1, 1.4 Hz, 1 H), 4.09 (t, $J$ = 7.0 Hz, 2 H), 2.58 (qt, $J$ = 6.9, 1.2 Hz, 2 H); HRFABMS calcd for C$_7$H$_9$BrN$_3$O$_2$ m/z [M + H]$^+$ 247.9858, 245.9878, found 247.9860, 245.9882.

Procedure B: 4-(2-Bromo-4-nitro-1H-imidazol-1-yl)butane-1,2-diol (10). Osmium tetroxide (3.20 mL of a 4% aqueous solution, 0.524 mmol) was added to a solution of alkene 9 (2.56 g, 10.4 mmol) and 4-methylmorpholine 4-oxide (1.83 g, 15.6 mmol) in CH$_2$Cl$_2$ (65 mL). The mixture was stirred at 20 °C for 4 h and the resulting precipitate was collected by filtration, washing with CH$_2$Cl$_2$ and water, to give 10 (2.29 g, 79%) as a cream solid: mp (THF/Et$_2$O/pentane) 99-101 °C; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.55 (s, 1 H), 4.77 (br d, $J$ = 5.0 Hz, 1 H), 4.58 (br t, $J$ = 5.6 Hz, 1 H), 4.20-4.07 (m, 2 H), 3.47-3.37 (m, 1 H), 3.34 (dt, $J$ = 10.7, 3.0 Hz, 2 H).
5.4 Hz, 1 H), 3.24 (dt, $J = 10.7, 5.9$ Hz, 1 H), 2.03-1.92 (m, 1 H), 1.76-1.63 (m, 1 H). Anal. (C$_{7}$H$_{10}$BrN$_{3}$O$_{4}$) C, H, N.

The remaining filtrate above was added to an ice-cold aqueous solution of sodium sulphite (100 mL), and the aqueous portion was saturated with salt and extracted with EtOAc (10 x 100 mL). The combined organic portions were evaporated to dryness under reduced pressure (at 30 °C), and the residue was chromatographed on silica gel. Elution with 0-50% EtOAc/petroleum ether first gave foreruns, and then further elution with EtOAc gave additional 10 (572 mg, 20%).

Procedure C: 4-(2-Bromo-4-nitro-1H-imidazol-1-yl)-1-[(triisopropylsilyl)oxy]butan-2-ol (11). Chlorotriisopropylsilane (2.35 mL, 11.0 mmol) was slowly added to a solution of diol 10 (2.86 g, 10.2 mmol) and imidazole (1.54 g, 22.6 mmol) in anhydrous DMF (25 mL) under N$_{2}$, and then the mixture was stirred at 20 °C for 2 d. The resulting mixture was added to ice-water (150 mL) and extracted with 50% EtOAc/petroleum ether (4 x 100 mL). The extracts were washed with water (100 mL) and then concentrated under reduced pressure (at 30 °C) and the remaining oil was chromatographed on silica gel. Elution with 0-20% EtOAc/petroleum ether first gave foreruns, and then further elution with 33% EtOAc/petroleum ether gave 11 (4.19 g, 94%) as a white solid: mp (CH$_{2}$Cl$_{2}$/pentane) 90-91 °C; $^1$H NMR (CDCl$_{3}$) $\delta$ 7.89 (s, 1 H), 4.24 (dd, $J = 7.7, 6.2$ Hz, 2 H), 3.74 (dd, $J = 9.6$, 3.5 Hz, 1 H), 3.67-3.58 (m, 1 H), 3.53 (dd, $J = 9.6, 6.8$ Hz, 1 H), 2.59 (d, $J = 3.8$ Hz, 1 H), 1.95-1.82 (m, 2 H), 1.18-1.02 (m, 21 H). Anal. (C$_{16}$H$_{30}$BrN$_{3}$O$_{4}$Si) C, H, N.

Procedure D: 2-Nitro-7-{{(triisopropylsilyl)oxy}methyl}-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (12). A solution of alcohol 11 (1.89 g, 4.33 mmol) in anhydrous DMF (35 mL) under N$_{2}$ at 0 °C was treated with 60% NaH (262 mg, 6.55 mmol) and then quickly degassed and resealed under N$_{2}$. The mixture was stirred at 0 °C for 25 min and at 20 °C for 3
h, then cooled (CO₂/acetone), quenched with ice/aqueous NaHCO₃ (10 mL), added to brine (100 mL), and extracted with CH₂Cl₂ (6 x 100 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-20% EtOAc/petroleum ether first gave foreruns, and then further elution with 0-4% EtOAc/CH₂Cl₂ gave 12 (1.48 g, 96%) as a pale yellow solid: mp (CH₂Cl₂/pentane) 121-123 °C; ¹H NMR (CDCl₃) δ 7.42 (s, 1 H), 4.49-4.40 (m, 1 H), 4.17 (ddd, J = 12.3, 5.8, 3.7 Hz, 1 H), 4.06 (ddd, J = 12.3, 10.3, 5.4 Hz, 1 H), 4.03 (dd, J = 10.7, 4.1 Hz, 1 H), 3.95 (dd, J = 10.7, 5.8 Hz, 1 H), 2.42-2.33 (m, 1 H), 2.33-2.20 (m, 1 H), 1.18-1.03 (m, 21 H).

Procedure E: (2-Nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl)methanol (13).
Silyl ether 12 (1.48 g, 4.16 mmol) was treated with a solution of 1% HCl in 95% EtOH (63 mL, 15.1 mmol). The mixture was stirred at 20 °C for 36 h and then cooled (CO₂/acetone) and neutralised with a solution of NH₃ in MeOH (8.0 mL of 2 M). The resulting mixture was evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-2% MeOH/CH₂Cl₂ first gave foreruns and then further elution with 2-4% MeOH/CH₂Cl₂ gave 13 (804 mg, 97%) as a light yellow solid: mp (THF/MeOH/CH₂Cl₂/hexane) 179-181 °C; ¹H NMR [CD₃SO] δ 8.04 (s, 1 H), 5.12 (t, J = 5.8 Hz, 1 H), 4.53-4.43 (m, 1 H), 4.13 (ddd, J = 12.5, 5.8, 3.0 Hz, 1 H), 4.04 (ddd, J = 12.4, 11.0, 5.1 Hz, 1 H), 3.70-3.59 (m, 2 H), 2.23-2.13 (m, 1 H), 2.10-1.96 (m, 1 H). Anal. (C₁₆H₂₉N₃O₄Si) C, H, N.

Procedure F: 2-Nitro-7-({[4-(trifluoromethoxy)benzyl]oxy}methyl)-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (14). A solution of alcohol 13 (40.2 mg, 0.202 mmol) in anhydrous DMF (2 mL) under N₂ at 0 °C was treated with 60% NaH (13.7 mg, 0.343 mmol) and then quickly degassed and resealed under N₂. 4-(Trifluoromethoxy)benzyl bromide (60
µL, 0.375 mmol) was added, and the mixture was stirred at 20 °C for 165 min, then cooled (CO₂/acetonitrile), quenched with ice/aqueous NaHCO₃ (10 mL), added to brine (40 mL), and extracted with CH₂Cl₂ (6 x 50 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-0.5% MeOH/CH₂Cl₂ first gave foreruns, and then further elution with 0.5% MeOH/CH₂Cl₂ gave 14 (52 mg, 69%) as a cream solid: mp (CH₂Cl₂/hexane) 158-160 °C; ¹H NMR [(CD₃)₂SO] δ 8.06 (s, 1 H), 7.47 (br d, J = 8.7 Hz, 2 H), 7.35 (br d, J = 7.9 Hz, 2 H), 4.77-4.69 (m, 1 H), 4.60 (s, 2 H), 4.13 (ddd, J = 12.5, 5.8, 3.0 Hz, 1 H), 4.05 (ddd, J = 12.5, 10.8, 5.2 Hz, 1 H), 3.76 (dd, J = 11.1, 3.9 Hz, 1 H), 3.73 (dd, J = 11.1, 5.1 Hz, 1 H), 2.27-2.17 (m, 1 H), 2.17-2.03 (m, 1 H); ¹³C NMR [(CD₃)₂SO] δ 147.9, 147.6 (q, J_C-F = 1.4 Hz), 142.0, 137.6, 129.2 (2 C), 120.9 (2 C), 120.1 (q, J_C-F = 256.0 Hz), 117.7, 76.7, 71.4, 70.9, 41.8, 22.6. Anal. (C₁₅H₁₄F₃N₃O₅) C, H, N.

**Synthesis of 25 (Scheme 1B):**

Procedure G: 7-[(4-Iodobenzyl)oxy|methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (24). A mixture of alcohol 13 (130 mg, 0.653 mmol) and 4-iodobenzyl bromide (262 mg, 0.882 mmol) in anhydrous DMF (5 mL) under N₂ at 0 °C was treated with 60% NaH (40 mg, 1.00 mmol) and then quickly degassed and resealed under N₂. The mixture was stirred at 20 °C for 2.5 h, then cooled (CO₂/acetonitrile), quenched with ice/aqueous NaHCO₃ (10 mL), added to brine (40 mL), and extracted with CH₂Cl₂ (5 x 50 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with CH₂Cl₂ first gave foreruns, and then further elution with 1-1.5% EtOAc/CH₂Cl₂ gave 24 (165 mg, 61%) as a cream solid: mp (CH₂Cl₂/hexane) 169-171 °C; ¹H NMR (CDCl₃) δ 7.68 (br d, J = 8.3 Hz, 2 H), 7.41 (s, 1 H), 7.05 (br d, J = 8.2 Hz, 2 H), 4.59-4.52 (m, 3 H), 4.14 (ddd, J = 12.3, 5.7, 3.8 Hz, 1 H), 4.05
(dd, $J = 12.3, 10.0, 5.6$ Hz, 1 H), 3.80 (dd, $J = 10.6, 4.3$ Hz, 1 H), 3.75 (dd, $J = 10.6, 5.0$ Hz, 1 H), 2.37-2.20 (m, 2 H); HRFABMS calcd for $C_{14}H_{13}IN_{3}O_{4} \ m/z [M + H]^+ \ 416.0107$, found 416.0105.

Procedure H: 7-[[4'-Fluoro[1,1'-biphenyl]-4-yl]methoxy[methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (25). A stirred mixture of iodide 24 (35 mg, 0.084 mmol), 4-fluorophenylboronic acid (15.8 mg, 0.113 mmol), and Pd(dppf)Cl$_2$ (2.1 mg, 0.003 mmol) in toluene (1.8 mL) and EtOH (0.7 mL) was degassed for 5 min (vacuum pump) and then N$_2$ was added. An aqueous solution of Na$_2$CO$_3$ (0.35 mL of 2 M, 0.70 mmol) was added by syringe and the mixture was stirred at 90 °C for 20 min, and then cooled, diluted with aqueous NaHCO$_3$ (50 mL), and extracted with CH$_2$Cl$_2$ (4 x 50 mL). The extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-1% EtOAc/CH$_2$Cl$_2$ first gave foreruns, and then further elution with 1-1.5% EtOAc/CH$_2$Cl$_2$ gave 25 (30.5 mg, 94%) as a cream solid: mp (CH$_2$Cl$_2$/pentane) 147-149 °C; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.07 (s, 1 H), 7.71 (br dd, $J = 8.9, 5.4$ Hz, 2 H), 7.64 (br d, $J = 8.2$ Hz, 2 H), 7.43 (br d, $J = 8.3$ Hz, 2 H), 7.29 (br t, $J = 8.9$ Hz, 2 H), 4.77-4.69 (m, 1 H), 4.61 (s, 2 H), 4.13 (ddd, $J = 12.5, 5.8, 3.0$ Hz, 1 H), 4.05 (ddd, $J = 12.4, 10.9, 5.2$ Hz, 1 H), 3.77 (dd, $J = 11.0, 3.9$ Hz, 1 H), 3.74 (dd, $J = 11.1, 5.1$ Hz, 1 H), 2.28-2.17 (m, 1 H), 2.17-2.03 (m, 1 H); $^{13}$C NMR [(CD$_3$)$_2$SO] $\delta$ 161.9 (d, $J_{C-F} = 244.4$ Hz), 148.0, 142.0, 138.4, 137.2, 136.3 (d, $J_{C-F} = 3.0$ Hz), 128.6 (d, $J_{C-F} = 8.1$ Hz, 2 C), 128.1 (2 C), 126.6 (2 C), 117.7, 115.7 (d, $J_{C-F} = 21.2$ Hz, 2 C), 76.8, 72.0, 70.8, 41.8, 22.6. Anal. (C$_{20}$H$_{18}$FN$_3$O$_4$) C, H, N.

Synthesis of 34 (Scheme 1C):

(7-Methyl-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl)methyl acetate (30). Acetic anhydride (3.60 mL, 38.1 mmol) was added to a suspension of alcohol 20 (see
Supporting Information) (807 mg, 3.79 mmol) in anhydrous pyridine (7.0 mL). The mixture was stirred at 20 °C for 38 h and then added to ice-water (150 mL) and extracted with CH₂Cl₂ (5 x 100 mL). The extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with CH₂Cl₂ first gave foreruns, and then further elution with 1-6% EtOAc/CH₂Cl₂ gave 30 (962 mg, 100%) as a cream solid: mp (CH₂Cl₂/pentane) 145-147 °C; ¹H NMR (CDCl₃) δ 7.44 (s, 1 H), 4.27 (d, J = 11.9 Hz, 1 H), 4.20 (d, J = 11.9 Hz, 1 H), 4.14 (dt, J = 12.7, 5.9 Hz, 1 H), 4.08 (ddd, J = 12.7, 8.3, 5.6 Hz, 1 H), 2.32 (ddd, J = 14.5, 8.3, 6.1 Hz, 1 H), 2.10 (dt, J = 14.5, 5.7 Hz, 1 H), 2.09 (s, 3 H), 1.50 (s, 3 H); HRFABMS calcd for C₁₀H₁₄N₃O₅ m/z [M + H]+ 256.0934, found 256.0941.

[(7R)-7-Methyl-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl]methyl acetate (31) and [(7S)-7-methyl-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl]methyl acetate (35). Racemic acetate 30 (990 mg) was separated into pure enantiomers by preparative chiral HPLC, using a CHIRALPAK IA column and an isocratic solvent system of 40% EtOH in hexane at a flow rate of 6 mL/min, to firstly give 35 (427 mg, 43%) as a cream solid, having identical ¹H NMR data to 30, that was used directly in the next step; [α]²⁶D -6.0 (c 1.00, CHCl₃).

Further elution of the HPLC column gave 31 (428 mg, 43%) as a cream solid that was used directly in the next step; ¹H NMR (CDCl₃) δ 7.44 (s, 1 H), 4.27 (d, J = 11.9 Hz, 1 H), 4.20 (d, J = 11.8 Hz, 1 H), 4.14 (dt, J = 12.7, 5.9 Hz, 1 H), 4.08 (ddd, J = 12.7, 8.3, 5.6 Hz, 1 H), 2.32 (ddd, J = 14.5, 8.3, 6.1 Hz, 1 H), 2.10 (dt, J = 14.5, 5.7 Hz, 1 H), 2.09 (s, 3 H), 1.50 (s, 3 H); [α]²⁶D 6.0 (c 1.00, CHCl₃).

Chiral HPLC (using a CHIRALPAK IA analytical column and eluting with 40% EtOH in hexane at 0.5 mL/min) determined that the ee of each enantiomer was 100%.

**Procedure 1:**  [(7R)-7-Methyl-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl]methanol (32). A stirred solution of ester 31 (427 mg, 1.67 mmol) in MeOH (36 mL) was
treated with K$_2$CO$_3$ (256 mg, 1.85 mmol) and then water (4 mL) was added dropwise. The mixture was stirred at 20 °C for 4 h and then cooled in ice and neutralised with 0.1 M HCl (37 mL). The resulting mixture was evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-1% MeOH/CH$_2$Cl$_2$ first gave foreruns and then further elution with 1-2.5% MeOH/CH$_2$Cl$_2$ gave 32 (343 mg, 96%) as a light yellow solid that was used directly in the next step; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.03 (s, 1 H), 5.23 (br t, $J = 5.4$ Hz, 1 H), 4.13 (dt, $J = 13.0$, 6.0 Hz, 1 H), 4.05 (ddd, $J = 12.9$, 8.1, 5.6 Hz, 1 H), 3.54 (dd, $J = 11.6$, 4.9 Hz, 1 H), 3.48 (dd, $J = 11.6$, 5.2 Hz, 1 H), 2.21 (ddd, $J = 14.4$, 8.1, 5.9 Hz, 1 H), 2.00 (dt, $J = 14.4$, 5.8 Hz, 1 H), 1.32 (s, 3 H); [$\alpha$]$^{27}_{D}$ -18.0 (c 1.00, DMF).

$(7R)$-7-[(4-Bromobenzyl)oxy]methyl]-7-methyl-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (33). Reaction of alcohol 32 with 4-bromobenzyl bromide (1.3 equiv) and NaH, using procedure G for 3 h, followed by chromatography of the product on silica gel, eluting with CH$_2$Cl$_2$ (foreruns) and then with 1% EtOAc/CH$_2$Cl$_2$, gave 33 (57%) as a white solid: mp (CH$_2$Cl$_2$/hexane) 157-159 °C; $^1$H NMR (CDCl$_3$) $\delta$ 7.46 (br d, $J = 8.3$ Hz, 2 H), 7.39 (s, 1 H), 7.12 (br d, $J = 8.3$ Hz, 2 H), 4.50 (s, 2 H), 4.09 (ddd, $J = 12.5$, 6.9, 6.0 Hz, 1 H), 4.01 (ddd, $J = 12.5$, 7.0, 6.0 Hz, 1 H), 3.62 (d, $J = 10.2$ Hz, 1 H), 3.58 (d, $J = 10.2$ Hz, 1 H), 2.37 (ddd, $J = 14.4$, 7.0, 6.0 Hz, 1 H), 2.10 (ddd, $J = 14.4$, 6.9, 6.1 Hz, 1 H), 1.46 (s, 3 H); [$\alpha$]$^{27}_{D}$ 31.0 (c 1.00, CHCl$_3$); HRFABMS calcd for C$_{15}$H$_{17}$BrN$_3$O$_4$ m/z [M + H]$^+$ 384.0382, 382.0402, found 384.0385, 382.0398.

$(7R)$-7-Methyl-2-nitro-7-[(4'-[trifluoromethoxy][1,1'-biphenyl]-4-yl)methoxy]methyl]-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (34). Reaction of bromide 33 with 4-(trifluoromethoxy)phenylboronic acid (1.5 equiv) and Pd(dppf)Cl$_2$ (0.15 equiv), using procedure H at 88 °C for 75 min, followed by chromatography of the product on silica gel, eluting with 0-0.5% EtOAc/CH$_2$Cl$_2$ (foreruns) and then with 0.5-1.5%
EtOAc/CH$_2$Cl$_2$, gave 34 (90%) as a cream solid: mp (CH$_2$Cl$_2$/hexane) 165-167 °C; $^1$H NMR (CDCl$_3$) $\delta$ 7.58 (br d, $J = 8.7$ Hz, 2 H), 7.52 (br d, $J = 8.2$ Hz, 2 H), 7.38 (s, 1 H), 7.32 (br d, $J = 8.1$ Hz, 2 H), 7.28 (br d, $J = 8.1$ Hz, 2 H), 4.61 (d, $J = 12.1$ Hz, 1 H), 4.58 (d, $J = 12.1$ Hz, 1 H), 4.11 (ddd, $J = 12.4$, 7.2, 5.8 Hz, 1 H), 4.01 (ddd, $J = 12.6$, 6.5, 6.1 Hz, 1 H), 3.67 (d, $J = 10.2$ Hz, 1 H), 3.63 (d, $J = 10.2$ Hz, 1 H), 2.40 (ddd, $J = 14.4$, 6.6, 6.1 Hz, 1 H), 2.13 (ddd, $J = 14.5$, 7.3, 6.0 Hz, 1 H), 1.48 (s, 3 H); [$\alpha$]$^2$D 37.0 (c 1.00, CHCl$_3$). Anal. (C$_{22}$H$_{20}$F$_3$N$_3$O$_5$) C, H, N.

**Synthesis of 44 (Scheme 2B):**

2-Chloro-1-(3-methylbut-3-en-1-yl)-4-nitro-1$H$-imidazole (41). Reaction of 2-chloro-4-nitro-1$H$-imidazole (40) with 4-iodo-2-methylbut-1-ene (15) (1.1 equiv) and powdered K$_2$CO$_3$ (2.0 equiv), using procedure A for 14 h, gave 41 (84%) as a white solid: mp (CH$_2$Cl$_2$/petroleum ether) 70-72 °C; $^1$H NMR (CDCl$_3$) $\delta$ 7.72 (s, 1 H), 4.93-4.87 (m, 1 H), 4.72-4.66 (m, 1 H), 4.13 (t, $J = 7.1$ Hz, 2 H), 2.52 (br t, $J = 7.0$ Hz, 2 H), 1.80 (br s, 3 H). Anal. (C$_8$H$_{10}$ClN$_3$O$_2$) C, H, N.

2-Chloro-1-[2-(2-methyloxiran-2-yl)ethyl]-4-nitro-1$H$-imidazole (42). 3-Chloroperoxybenzoic acid (14.4 g of 70%, 58.4 mmol) was added to a mixture of alkene 41 (10.4 g, 48.2 mmol) and disodium hydrogen phosphate (10.4 g, 73.3 mmol) in CH$_2$Cl$_2$ (300 mL) at 0 °C. The mixture was stirred at 20 °C for 4 h and then additional $m$-CPBA (2.40 g, 9.74 mmol) and CH$_2$Cl$_2$ (50 mL) were added. The resulting mixture was stirred at 20 °C for a further 14 h, and then cooled to -20 °C and washed with an ice-cold aqueous solution of sodium sulphite (200 mL of 10%), back-extracting with CH$_2$Cl$_2$ (2 x 200 mL). The organic portions were sequentially washed with aqueous NaHCO$_3$ (200 mL) and brine (100 mL), and then combined and concentrated under reduced pressure, and the remaining oil was chromatographed on silica gel. Elution with 3:1 CH$_2$Cl$_2$/petroleum ether first gave foreruns,
and then further elution with 3:1 CH₂Cl₂/petroleum ether and 0-2.5% EtOAc/CH₂Cl₂ gave 42 (10.6 g, 95%) as a cream solid: mp (CH₂Cl₂/petroleum ether) 87-89 °C; ¹H NMR (CDCl₃) δ 7.79 (s, 1 H), 4.13 (t, J = 7.6 Hz, 2 H), 2.67 (br d, J = 4.4 Hz, 1 H), 2.62 (br d, J = 4.3 Hz, 1 H), 2.19 (dt, J = 14.3, 7.7 Hz, 1 H), 2.04 (dt, J = 14.3, 7.4 Hz, 1 H), 1.40 (s, 3 H). Anal. (C₈H₁₀ClN₃O₃) C, H, N.

**Procedure J:** 4-(2-Chloro-4-nitro-1H-imidazol-1-yl)-2-methyl-1-[4-(trifluoromethoxy)phenoxy]butan-2-ol (43). 4-(Trifluoromethoxy)phenol (0.280 mL, 2.16 mmol) was added to a mixture of epoxide 42 (200 mg, 0.863 mmol) and powdered K₂CO₃ (422 mg, 3.05 mmol) in anhydrous MEK (2.0 mL) under N₂, and then the mixture was stirred at 82 °C for 10 h. The resulting cooled mixture was diluted with water (50 mL) and extracted with CH₂Cl₂ (4 x 50 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with CH₂Cl₂ first gave foreruns, and then further elution with 0-2% EtOAc/CH₂Cl₂ gave 43 (272 mg, 77%) as a pale yellow oil; ¹H NMR (CDCl₃) δ 7.81 (s, 1 H), 7.17 (br d, J = 9.1 Hz, 2 H), 6.90 (br d, J = 9.2 Hz, 2 H), 4.33-4.20 (m, 2 H), 3.85 (d, J = 9.0 Hz, 1 H), 3.82 (d, J = 9.0 Hz, 1 H), 2.23 (ddd, J = 13.8, 9.3, 6.5 Hz, 1 H), 2.21 (s, 1 H), 2.04 (ddd, J = 13.8, 9.6, 6.6 Hz, 1 H), 1.40 (s, 3 H); HRESIMS calcd for C₁₅H₁₆ClF₃N₃O₅ m/z [M + H]⁺ 412.0697, 410.0725, found 412.0700, 410.0722.

7-Methyl-2-nitro-7-[[4-(trifluoromethoxy)phenoxy]methyl]-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (44). Reaction of alcohol 43 with NaH (1.7 equiv), using procedure D for 2 h, followed by chromatography of the product on silica gel, eluting with CH₂Cl₂, gave 44 (61%) as a cream solid: mp (CH₂Cl₂/pentane) 134-136 °C; ¹H NMR [(CD₃)₂SO] δ 8.10 (s, 1 H), 7.31 (br d, J = 9.0 Hz, 2 H), 7.07 (br d, J = 9.2 Hz, 2 H), 4.20 (s, 2 H), 4.19 (dt, J = 13.3, 6.1 Hz, 1 H), 4.13 (ddd, J = 13.2, 8.1, 5.6 Hz, 1 H), 2.38 (ddd, J =
14.4, 7.9, 6.2 Hz, 1 H), 2.18 (dt, $J = 14.4, 5.8$ Hz, 1 H), 1.49 (s, 3 H); $^{13}$C NMR [(CD$_3$)$_2$SO] $\delta$ 157.0, 147.2, 142.2, 142.1 (q, $J_{C-F} = 1.6$ Hz), 122.5 (2 C), 120.1 (q, $J_{C-F} = 255.2$ Hz), 117.7, 115.9 (2 C), 80.4, 72.4, 39.5, 27.0, 21.3. Anal. (C$_{15}$H$_{14}$F$_3$N$_3$O$_5$) C, H, N.

**Synthesis of 55 (Scheme 2A):**

**Procedure K:** 7-[(4-Iodophenoxy)methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (48). DEAD (0.270 mL, 1.74 mmol) was added dropwise to a stirred solution of alcohol 13 (251 mg, 1.26 mmol), 4-iodophenol (377 mg, 1.71 mmol), and PPh$_3$ (448 mg, 1.71 mmol) in anhydrous THF (3 mL) under N$_2$ at 0 $^\circ$C. After being stirred at 20 $^\circ$C for 32 h, the mixture was concentrated under reduced pressure to give an oil, which was chromatographed on silica gel. Elution with CH$_2$Cl$_2$ first gave foreruns, and then further elution with 0-2% EtOAc/CH$_2$Cl$_2$ gave the crude product, which was further purified by chromatography on silica gel. Elution with 33-50% EtOAc/petroleum ether first gave foreruns, and then further elution with 10% MeOH/CH$_2$Cl$_2$ gave 48 (433 mg, 86%) as a cream solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 224-227 $^\circ$C; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.08 (s, 1 H), 7.62 (br d, $J = 9.0$ Hz, 2 H), 6.86 (br d, $J = 9.0$ Hz, 2 H), 4.94-4.85 (m, 1 H), 4.31 (dd, $J = 11.1$, 3.4 Hz, 1 H), 4.25 (dd, $J = 11.1$, 5.8 Hz, 1 H), 4.18 (ddd, $J = 12.6$, 5.8, 3.0 Hz, 1 H), 4.09 (ddd, $J = 12.5$, 10.8, 5.2 Hz, 1 H), 2.35-2.26 (m, 1 H), 2.25-2.12 (m, 1 H). Anal. (C$_{13}$H$_{12}$N$_3$O$_4$) C, H, N.

**Procedure L:** 7-[(4-(6-Fluoropyridin-3-yl)phenoxy)methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (55). A stirred mixture of iodide 48 (70.3 mg, 0.175 mmol), (6-fluoropyridin-3-yl)boronic acid (42.3 mg, 0.300 mmol), and Pd(dppf)Cl$_2$ (19.5 mg, 0.0266 mmol) in DMF (2.3 mL), toluene (1.5 mL), and EtOH (1.0 mL) was degassed for 8 min (vacuum pump) and then N$_2$ was added. An aqueous solution of KHCO$_3$ (0.40 mL of 2 M, 0.80 mmol) was added by syringe and the stirred mixture was again degassed for 9 min, and
then N$_2$ was added. The resulting mixture was stirred at 85 °C for 2 h, and then cooled, diluted with aqueous NaHCO$_3$ (50 mL), and extracted with CH$_2$Cl$_2$ (6 x 50 mL). The extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-4% EtOAc/CH$_2$Cl$_2$ first gave foreruns, and then further elution with 4-7% EtOAc/CH$_2$Cl$_2$ gave 55 (61 mg, 94%) as a cream solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 197–198 °C; $^1$H NMR [(CD$_3$)$_2$SO] δ 8.51 (br d, J = 2.6 Hz, 1 H), 8.24 (td, J = 8.2, 2.6 Hz, 1 H), 8.10 (s, 1 H), 7.69 (br d, J = 8.8 Hz, 2 H), 7.24 (dd, J = 8.6, 2.6 Hz, 1 H), 7.13 (br d, J = 8.8 Hz, 2 H), 4.99-4.88 (m, 1 H), 4.39 (dd, J = 11.1, 3.3 Hz, 1 H), 4.33 (dd, J = 11.1, 5.8 Hz, 1 H), 4.20 (ddd, J = 12.5, 5.7, 2.9 Hz, 1 H), 4.11 (dd, J = 12.4, 10.9, 5.2 Hz, 1 H), 2.39-2.29 (m, 1 H), 2.29-2.15 (m, 1 H); $^{13}$C NMR [(CD$_3$)$_2$SO] δ 162.2 (d, J$_{C,F}$ = 235.1 Hz), 158.2, 147.8, 144.8 (d, J$_{C,F}$ = 15.1 Hz), 142.1, 139.8 (d, J$_{C,F}$ = 8.0 Hz), 133.7 (d, J$_{C,F}$ = 4.6 Hz), 128.7, 128.1 (2 C), 117.8, 115.3 (2 C), 109.5 (d, J$_{C,F}$ = 37.7 Hz), 76.0, 68.8, 41.7, 22.4. Anal. (C$_{18}$H$_{15}$FN$_4$O$_4$) C, H, N.

Synthesis of 59 (Scheme 2C):

Procedure M: 7-[(5-Bromopyridin-2-yl)oxy]methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (58). A mixture of alcohol 13 (500 mg, 2.51 mmol) and 5-bromo-2-fluoropyridine (57) (0.52 mL, 5.05 mmol) in anhydrous DMF (10 mL) under N$_2$ at 0 °C was treated with 60% NaH (151 mg, 3.78 mmol) and then quickly degassed and resealed under N$_2$. Further 57 (0.52 mL, 5.05 mmol) was added and the mixture was stirred at 20 °C for 2.5 h. The resulting mixture was cooled (CO$_2$/acetone), quenched with ice/aqueous NaHCO$_3$ (20 mL), and then added to brine (100 mL) and extracted with CH$_2$Cl$_2$ (8 x 100 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C) and the residue was chromatographed on silica gel. Elution with 0-1% EtOAc/CH$_2$Cl$_2$ first gave foreruns, and then further elution with 2-4% EtOAc/CH$_2$Cl$_2$ gave 58 (778 mg, 87%) as a
white solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 182-184 °C; $^1$H NMR [(CD$_3$)$_2$SO] δ 8.30 (br d, $J = 2.6$ Hz, 1 H), 8.07 (s, 1 H), 7.94 (dd, $J = 8.8$, 2.6 Hz, 1 H), 6.91 (br d, $J = 8.8$ Hz, 1 H), 4.95-4.86 (m, 1 H), 4.58 (dd, $J = 12.0$, 3.3 Hz, 1 H), 4.52 (dd, $J = 12.0$, 6.0 Hz, 1 H), 4.17 (ddd, $J = 12.6$, 5.8, 2.8 Hz, 1 H), 4.09 (ddd, $J = 12.5$, 11.0, 5.2 Hz, 1 H), 2.35-2.25 (m, 1 H), 2.24-2.10 (m, 1 H). Anal. (C$_{12}$H$_{11}$BrN$_4$O$_4$) C, H, N.

Procedure N: 7-[(5-(4-Fluorophenyl)pyridin-2-yl)oxy]methyl)-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (59). A stirred mixture of bromide 58 (150 mg, 0.422 mmol), 4-fluorophenylboronic acid (117 mg, 0.836 mmol), and Pd(dppf)Cl$_2$ (83.1 mg, 0.114 mmol) in DMF (4.5 mL), toluene (3 mL), and EtOH (2 mL) was degassed for 10 min (vacuum pump) and then N$_2$ was added. An aqueous solution of Na$_2$CO$_3$ (1.05 mL of 2 M, 2.1 mmol) was added by syringe, the stirred mixture was again degassed for 10 min, and then N$_2$ was added. The resulting mixture was stirred at 89 °C for 2.5 h and then cooled, diluted with aqueous NaHCO$_3$ (50 mL), and extracted with CH$_2$Cl$_2$ (6 x 50 mL). The combined extracts were evaporated to dryness under reduced pressure (at 30 °C), and the residue was chromatographed on silica gel. Elution with 0-3% EtOAc/CH$_2$Cl$_2$ first gave foreruns, and then further elution with 3% EtOAc/CH$_2$Cl$_2$ gave 59 (143 mg, 91%) as a cream solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 180-181 °C; $^1$H NMR [(CD$_3$)$_2$SO] δ 8.47 (br d, $J = 2.6$ Hz, 1 H), 8.09 (s, 1 H), 8.05 (dd, $J = 8.6$, 2.6 Hz, 1 H), 7.71 (br dd, $J = 8.9$, 5.4 Hz, 2 H), 7.30 (br t, $J = 8.9$ Hz, 2 H), 6.98 (br d, $J = 8.6$ Hz, 1 H), 4.99-4.90 (m, 1 H), 4.64 (dd, $J = 12.0$, 3.4 Hz, 1 H), 4.58 (dd, $J = 12.0$, 6.0 Hz, 1 H), 4.19 (ddd, $J = 12.5$, 5.8, 2.7 Hz, 1 H), 4.10 (ddd, $J = 12.5$, 11.1, 5.1 Hz, 1 H), 2.38-2.28 (m, 1 H), 2.27-2.13 (m, 1 H); $^{13}$C NMR [(CD$_3$)$_2$SO] δ 162.1, 161.9 (d, $J_{C-F} = 244.4$ Hz), 147.8, 144.5, 142.0, 137.9, 133.3 (d, $J_{C-F} = 3.1$ Hz), 128.9, 128.4 (d, $J_{C-F} = 8.1$ Hz, 2 C), 117.8, 115.8 (d, $J_{C-F} = 21.5$ Hz, 2 C), 110.8, 76.0, 66.3, 41.7, 22.5. Anal. (C$_{18}$H$_{13}$FN$_4$O$_4$) C, H, N.
**Synthesis of 79 (Scheme 3B):**

2-Chloro-1-\{2-[(4R)-2,2-dimethyl-1,3-dioxolan-4-yl]ethyl\}-4-nitro-1\(\text{H}\)-imidazole (73).

Reaction of 2-chloro-4-nitro-1\(\text{H}\)-imidazole (40) with (4R)-4-(2-iodoethyl)-2,2-dimethyl-1,3-dioxolane\(^{33}\) (72) (0.96 equiv) and powdered \(\text{K}_2\text{CO}_3\) (1.03 equiv), using procedure A for 3 d, followed by chromatography of the product on silica gel, eluting with 0-33% Et\(_2\)O/petroleum ether (foreruns) and then with 33-50% Et\(_2\)O/petroleum ether, gave 73 (74\%) as a light yellow solid: mp (Et\(_2\)O/pentane) 73-75 °C; \(^1\)H NMR (CDCl\(_3\)) \(\delta\) 7.81 (s, 1 H), 4.23 (ddd, \(J = 14.2, 7.7, 5.3\) Hz, 1 H), 4.18 (ddd, \(J = 14.2, 8.0, 7.1\) Hz, 1 H), 4.10 (dd, \(J = 7.9, 6.1\) Hz, 1 H), 4.09-4.01 (m, 1 H), 3.60 (dd, \(J = 7.8, 5.7\) Hz, 1 H), 2.12-2.01 (m, 1 H), 2.01-1.90 (m, 1 H), 1.43 (s, 3 H), 1.36 (s, 3 H); \([\alpha]^{26}_D\) 39.2 (c 1.020, CHCl\(_3\)). Anal. (C\(_{10}\)H\(_{14}\)ClN\(_3\)O\(_4\)) C, H, N.

**Procedure O:** (2R)-4-(2-Chloro-4-nitro-1\(\text{H}\)-imidazol-1-yl)butane-1,2-diol (74). Dilute HCl (13 mL of a 1 M solution, 13.0 mmol) was added dropwise to a stirred solution of acetonide 73 (2.86 g, 10.4 mmol) in MeOH (39 mL) at 0 °C. The mixture was stirred at 20 °C for 6 h and then cooled in ice, treated with \(\text{K}_2\text{CO}_3\) (0.90 g, 6.51 mmol), and stirred until the neutralisation was complete. Following filtration to remove inorganic material (washing with MeOH), the solvents were removed under reduced pressure (at 30 °C), and the residue was chromatographed on silica gel. Elution with 0-67% EtOAc/petroleum ether first gave foreruns, and then further elution with EtOAc gave 74 (2.39 g, 98\%) as a cream solid: mp (MeOH/CH\(_2\)Cl\(_2\)/hexane) 115-117 °C; \(^1\)H NMR [(CD\(_3\))\(_2\)SO] \(\delta\) 8.55 (s, 1 H), 4.79 (d, \(J = 5.0\) Hz, 1 H), 4.60 (t, \(J = 5.6\) Hz, 1 H), 4.21-4.08 (m, 2 H), 3.45-3.36 (m, 1 H), 3.36-3.29 (m, 1 H), 3.22 (dt, \(J = 10.7, 5.9\) Hz, 1 H), 2.03-1.91 (m, 1 H), 1.75-1.62 (m, 1 H); \([\alpha]^{24}_D\) 29.4 (c 2.008, DMF). Anal. (C\(_{10}\)H\(_{14}\)ClN\(_3\)O\(_4\)) C, H, N.

**Procedure P:** (2R)-4-(2-Chloro-4-nitro-1\(\text{H}\)-imidazol-1-yl)-2-hydroxybutyl 4-methylbenzenesulfonate (75). A solution of tosyl chloride (2.28 g, 12.0 mmol) in anhydrous pyridine (3 mL, then 2 x 1.5 mL to rinse) was added dropwise to a stirred solution of diol 74
(2.35 g, 9.97 mmol) in anhydrous pyridine (5 mL) under N₂ at -10 °C. The mixture was stirred at -10 to 0 °C for 2 h and then at 20 °C for 13 h. The resulting solution was cooled in ice and then added to ice-water (100 mL) and extracted with CH₂Cl₂ (4 x 100 mL). The combined extracts were concentrated to dryness under reduced pressure (at 30 °C) and the remaining oil was chromatographed on silica gel. Elution with 0-2% EtOAc/CH₂Cl₂ first gave foreruns, and then further elution with 2-50% EtOAc/CH₂Cl₂ gave 75 (3.38 g, 87%) as a cream foam that was used directly in the next step; ¹H NMR (CDCl₃) δ 7.78 (s, 1 H), 7.78 (br d, J = 8.3 Hz, 2 H), 7.37 (br d, J = 8.0 Hz, 2 H), 4.22 (dd, J = 7.7, 6.0 Hz, 2 H), 4.04 (dd, J = 10.5, 3.4 Hz, 1 H), 3.95 (dd, J = 10.5, 6.6 Hz, 1 H), 3.87-3.78 (m, 1 H), 2.62 (br d, J = 4.3 Hz, 1 H), 2.47 (s, 3 H), 1.99-1.83 (m, 2 H); APCI MS m/z 392, 390 [M + H]⁺.

Procedure Q: 2-Chloro-4-nitro-1-[2-[(2R)-oxiran-2-yl]ethyl]-1H-imidazole (76). 1,8-Diazabicyclo[5.4.0]undec-7-ene (1.45 mL, 9.70 mmol) was added dropwise to a stirred solution of tosylate 75 (3.38 g, 8.67 mmol) in anhydrous CH₂Cl₂ (32 mL) under N₂ at 0 °C. The mixture was stirred at 0 °C for 3 h, at 0-20 °C for 2 h, and then at 20 °C for 3 h. The resulting solution was added to a mixture of ice and brine (100 mL) and extracted with CH₂Cl₂ (4 x 100 mL). The combined extracts were concentrated to dryness under reduced pressure (at 30 °C) and the remaining oil was chromatographed on silica gel. Elution with CH₂Cl₂ first gave foreruns, and then further elution with CH₂Cl₂ gave 76 (1.78 g, 94%) as a cream solid (after freezing): mp (CH₂Cl₂/pentane) 59-61 °C; ¹H NMR (CDCl₃) δ 7.81 (s, 1 H), 4.29-4.15 (m, 2 H), 2.99-2.91 (m, 1 H), 2.86 (dd, J = 4.7, 4.0 Hz, 1 H), 2.54 (dd, J = 4.8, 2.6 Hz, 1 H), 2.36-2.25 (m, 1 H), 1.87-1.76 (m, 1 H); [α]25D 43.6 (c 1.009, CHCl₃). Anal. (C₇H₈ClN₃O₃) C, H, N.

Procedure R: (2R)-1-[(6-Bromopyridin-3-yl)oxy]-4-(2-chloro-4-nitro-1H-imidazol-1-yl)butan-2-ol (77). A mixture of epoxide 76 (1.76 g, 8.07 mmol), 6-bromopyridin-3-ol (68)
(2.82 g, 16.2 mmol), and powdered K$_2$CO$_3$ (2.23 g, 16.1 mmol) in anhydrous MEK (21 mL) under N$_2$ was stirred at 80-82 °C for 42 h. The resulting cooled mixture was added to water (100 mL), washing in residues with MeOH/CH$_2$Cl$_2$, and then extracted with 10% MeOH/CH$_2$Cl$_2$ (3 x 100 mL) and 25% EtOAc/CH$_2$Cl$_2$ (3 x 100 mL). The combined extracts were concentrated to dryness under reduced pressure and the remaining oil was chromatographed on silica gel. Elution with 0-40% EtOAc/petroleum ether first gave foreruns, and then further elution with 50% EtOAc/petroleum ether gave 77 (1.71 g, 54%) as a cream solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 134-135 °C; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.58 (s, 1 H), 8.12 (d, $J$ = 3.1 Hz, 1 H), 7.54 (d, $J$ = 8.7 Hz, 1 H), 7.39 (dd, $J$ = 8.8, 3.2 Hz, 1 H), 5.30 (d, $J$ = 4.9 Hz, 1 H), 4.27-4.14 (m, 2 H), 3.99 (dd, $J$ = 10.0, 4.8 Hz, 1 H), 3.95 (dd, $J$ = 10.0, 5.5 Hz, 1 H), 3.86-3.77 (m, 1 H), 2.11-2.00 (m, 1 H), 1.95-1.83 (m, 1 H); [$\alpha$]$^D_{24}$ 7.95 (c 1.006, DMF). Anal. (C$_{12}$H$_{12}$BrClN$_4$O$_4$) C, H, N.

Further elution of the above column with 4:1 EtOAc/petroleum ether gave impurities and then elution with EtOAc gave crude oxazine 78 (0.46 g), which was chromatographed again on silica gel. Elution with 0-0.4% MeOH/CH$_2$Cl$_2$ first gave foreruns, and then elution with 0.5% MeOH/CH$_2$Cl$_2$ gave purified 78 (305 mg, 11%) as a cream solid (see data below).

(7R)-7-[[(6-Bromopyridin-3-yl)oxy]methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (78). Reaction of alcohol 77 with NaH (1.4 equiv), using procedure D (but extracting the product four times with 10% MeOH/CH$_2$Cl$_2$ and then four times with CH$_2$Cl$_2$), followed by chromatography of the product on silica gel, eluting with 0-0.5% MeOH/CH$_2$Cl$_2$ (foreruns) and then with additional 0.5% MeOH/CH$_2$Cl$_2$, gave 78 (94%) as a cream solid: mp (MeOH/CH$_2$Cl$_2$/hexane) 211-212 °C; $^1$H NMR [(CD$_3$)$_2$SO] $\delta$ 8.19 (d, $J$ = 3.1 Hz, 1 H), 8.10 (s, 1 H), 7.59 (br d, $J$ = 8.7 Hz, 1 H), 7.47 (dd, $J$ = 8.8, 3.2 Hz, 1 H), 4.96-4.89 (m, 1 H), 4.43 (dd, $J$ = 11.2, 3.2 Hz, 1 H), 4.37 (dd, $J$ = 11.2, 5.8 Hz, 1 H), 4.18 (dd, $J$ = 12.5, 5.8, 2.9 Hz, 1 H).
1 H), 4.09 (ddd, J = 12.5, 10.9, 5.2 Hz, 1 H), 2.35-2.26 (m, 1 H), 2.25-2.13 (m, 1 H); [α]$_{D}^{24}$ -61.9 (c 1.002, DMF). Anal. (C$_{12}$H$_{11}$BrN$_{4}$O$_{4}$) C, H, N.

(7R)-7-(((6-(4-Fluorophenyl)pyridin-3-yl)oxy)methyl)-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (79). Reaction of bromide 78 with 4-fluorophenylboronic acid (1.9 equiv) and Pd(dppf)Cl$_{2}$ (0.25 equiv), using procedure N at 87 °C for 200 min (but extracting the product three times with 10% MeOH/CH$_{2}$Cl$_{2}$ and then three times with CH$_{2}$Cl$_{2}$), followed by chromatography of the product on silica gel, eluting with 0-0.5% MeOH/CH$_{2}$Cl$_{2}$ (forersuns) and then with 0.5-0.67% MeOH/CH$_{2}$Cl$_{2}$, gave 79 (87%) as a cream solid: mp (MeOH/CH$_{2}$Cl$_{2}$/hexane) 205-208 °C; $^{1}$H NMR [(CD$_{3}$)$_{2}$SO] $\delta$ 8.43 (d, J = 2.9 Hz, 1 H), 8.11 (s, 1 H), 8.07 (br dd, J = 8.9, 5.5 Hz, 2 H), 7.94 (d, J = 8.8 Hz, 1 H), 7.56 (dd, J = 8.8, 3.0 Hz, 1 H), 7.28 (br t, J = 8.9 Hz, 2 H), 5.00-4.91 (m, 1 H), 4.47 (dd, J = 11.2, 3.2 Hz, 1 H), 4.41 (dd, J = 11.2, 5.8 Hz, 1 H), 4.20 (ddd, J = 12.5, 5.7, 2.9 Hz, 1 H), 4.11 (ddd, J = 12.4, 11.0, 5.2 Hz, 1 H), 2.39-2.29 (m, 1 H), 2.29-2.16 (m, 1 H); [α]$_{D}^{23}$ -62.6 (c 1.006, DMF). Anal. (C$_{18}$H$_{15}$FN$_{4}$O$_{4}$) C, H, N.

Compounds of Table 2. The following section details the syntheses of compounds 142 and 160 of Table 2, via representative procedures and key intermediates, as described in Scheme 5. For the syntheses of all of the other compounds in Table 2, please refer to the Supporting Information.

Synthesis of 142 (Scheme 5A):

Procedure S: 4-(2-Chloro-4-nitro-1H-imidazol-1-yl)-1-[4-(4-fluorophenyl)piperazin-1-yl]butan-2-ol (141). A mixture of epoxide 67 (see the Supporting Information) (150 mg, 0.689 mmol) and 1-(4-fluorophenyl)piperazine (140) (186 mg, 1.03 mmol) in MEK (3 mL) in a sealed vial was stirred at 70 °C for 51 h. The resulting cooled mixture was transferred to a flask (in CH$_{2}$Cl$_{2}$) and evaporated to dryness under reduced pressure (at 30 °C), and then the
residue was chromatographed on silica gel. Elution with 0-0.3% MeOH/CH₂Cl₂ first gave foreruns, and then further elution with 1-2% MeOH/CH₂Cl₂ gave 141 (225 mg, 82%) as a pale yellow oil; ¹H NMR (CDCl₃) δ 7.87 (s, 1 H), 6.97 (br dd, J = 9.2, 8.3 Hz, 2 H), 6.87 (br dd, J = 9.2, 4.6 Hz, 2 H), 4.27 (dd, J = 8.2, 5.7 Hz, 2 H), 3.67-3.58 (m, 1 H), 3.57 (v br s, 1 H), 3.19-3.07 (m, 4 H), 2.85-2.77 (m, 2 H), 2.59-2.51 (m, 2 H), 2.41 (dd, J = 12.3, 4.0 Hz, 1 H), 2.37 (dd, J = 12.3, 9.5 Hz, 1 H), 1.98-1.87 (m, 1 H), 1.82-1.70 (m, 1 H); HRESIMS calcd for C₁₇H₂₂ClFN₅O₃ m/z [M + H]⁺ 400.1366, 398.1390, found 400.1370, 398.1397.

7-[(4-(4-Fluorophenyl)piperazin-1-yl)methyl]-2-nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazine (142). Reaction of alcohol 141 with NaH, using procedure D at 40 °C for 2 h, followed by chromatography of the product on silica gel, eluting with 0-0.5% MeOH/CH₂Cl₂ (foreruns) and then with 1% MeOH/CH₂Cl₂, gave 142 (67%) as a pale yellow solid: mp (CH₂Cl₂/hexane) 213-215 °C; ¹H NMR [(CD₃)₂SO] δ 8.07 (s, 1 H), 7.04 (br dd, J = 9.2, 8.6 Hz, 2 H), 6.94 (br dd, J = 9.3, 4.7 Hz, 2 H), 4.79-4.68 (m, 1 H), 4.13 (ddd, J = 12.6, 5.9, 2.9 Hz, 1 H), 4.05 (ddd, J = 12.5, 10.8, 5.1 Hz, 1 H), 3.13-3.03 (m, 4 H), 2.73 (dd, J = 13.5, 6.6 Hz, 1 H), 2.70-2.60 (m, 5 H), 2.29-2.19 (m, 1 H), 2.09-1.95 (m, 1 H); ¹³C NMR [(CD₃)₂SO] δ 156.0 (d, Jₐ-C = 235.6 Hz), 148.0, 147.9 (d, Jₐ-C = 1.6 Hz), 142.1, 117.7, 117.1 (d, Jₐ-C = 7.6 Hz, 2 C), 115.2 (d, Jₐ-C = 21.7 Hz, 2 C), 76.0, 60.5, 53.2 (2 C), 49.0 (2 C), 41.8, 24.3. Anal. (C₁₇H₂₀FN₅O₃) C, H, N.

**Synthesis of 160 (Scheme 5C):**

**Procedure T:** (2-Nitro-6,7-dihydro-5H-imidazo[2,1-b][1,3]oxazin-7-yl)methyl 4-(4-fluorophenyl)piperazine-1-carboxylate (160). Triphosgene (145 mg, 0.489 mmol) was added to a mixture of alcohol 13 (192 mg, 0.964 mmol) and triethylamine (0.40 mL, 2.87 mmol) in anhydrous THF (15 mL). The mixture was stirred at 20 °C for 30 min and then a solution of 1-(4-fluorophenyl)piperazine (140) (347 mg, 1.93 mmol) in anhydrous THF (5
mL) was added. The resulting mixture was stirred at 20 °C for 2 h and then quenched with saturated NH₄Cl (100 mL) and extracted with EtOAc (2 x 100 mL). The combined extracts were evaporated to dryness under reduced pressure and the residue was chromatographed on silica gel. Elution with 0-2% MeOH/CH₂Cl₂ gave crude material, which was successively recrystallized from CH₂Cl₂/hexane and EtOAc/hexane, to give 160 (130 mg, 33%) as a cream solid: mp 177-180 °C; ¹H NMR [(CD₃)₂SO] δ 8.08 (s, 1 H), 7.06 (br dd, J = 9.1, 8.7 Hz, 2 H), 6.97 (br dd, J = 9.2, 4.7 Hz, 2 H), 4.84-4.73 (m, 1 H), 4.37 (dd, J = 12.2, 3.2 Hz, 1 H), 4.29 (dd, J = 12.2, 5.8 Hz, 1 H), 4.15 (ddd, J = 12.5, 5.8, 2.7 Hz, 1 H), 4.06 (ddd, J = 12.4, 11.3, 5.1 Hz, 1 H), 3.61-3.45 (m, 4 H), 3.14-2.98 (m, 4 H), 2.30-2.20 (m, 1 H), 2.17-2.03 (m, 1 H); ¹³C NMR [(CD₃)₂SO] δ 156.3 (d, J_C-F = 236.3 Hz), 154.1, 147.8, 147.7 (d, J_C-F = 1.6 Hz), 142.0, 117.9 (d, J_C-F = 7.5 Hz, 2 C), 117.7, 115.3 (d, J_C-F = 22.0 Hz, 2 C), 75.8, 65.5, 49.1 (2 C), 43.4 (2 C), 41.7, 22.3. Anal. (C₁₈H₂₀F₅N₅O₅) C, H, N.

**Minimum Inhibitory Concentration Assays (MABA and LORA).** These were carried out according to the published protocols.⁴¹,⁵⁶

**In Vitro Parasite Growth Inhibition Assays.** The activity of test compounds against the amastigote stage of the *L. don* parasite was assessed at CDRI using a mouse macrophage-based luciferase assay, performed according to the reported procedures.¹⁰ Further assays measuring the growth inhibitory action of compounds against *L. inf*, *T. cruzi*, and *T. brucei*, and determining any cytotoxic effects on human lung fibroblasts (MRC-5 cells), were conducted at the University of Antwerp (LMPH), as detailed in a recent article.⁴⁰

**Solubility Determinations. Method A.** The solid compound sample was mixed with water or 0.1 M HCl (enough to make a 2 mM solution) in an Eppendorf tube, and the suspension was sonicated for 15 min and then centrifuged at 13000 rpm for 6 min. An aliquot of the clear supernatant was diluted 2-fold with water (or 0.1 M HCl), and then HPLC was conducted. The kinetic solubility was calculated by comparing the peak area obtained with that from a
standard solution of the compound in DMSO (after allowing for varying dilution factors and injection volumes).

Method B. The thermodynamic solubility of compound 4 at pH 7.4 was measured by Drugabilis, 5 rue Jean-Baptiste Clément, 92290 Châtenay-Malabry, France. The dry powder was stirred with 0.12 M phosphate buffer (pH 7.4) at 20 °C for 24 h. After filtration using a 0.22 μm PVDF membrane filter, the concentration of 4 was determined by HPLC with reference to a standard solution; the final value is the mean from two independent assays.

Method C. The thermodynamic solubility of compound 79 at pH 6.5 and 5.0 was measured by WuXi AppTec (Shanghai) Co., Ltd., 288 FuTe ZhongLu, WaiGaoQiao Free Trade Zone, Shanghai 200131, China. Aliquots of the compound DMSO stock (10 mM) were transferred to fasted state simulated intestinal fluid buffer (pH 6.5) or fed state simulated intestinal fluid buffer (pH 5.0) and the mixtures were shaken for 24 h at room temperature. Following sampling by a Whatman filter device, the compound concentrations were determined by UV spectroscopy with reference to three calibration standards (2, 100, and 200 μM).

Method D. The thermodynamic solubility of compound 79 at pH 7.4 was measured by Syngene International Ltd., Plot No. 2 & 3 Biocon Park, Jigani Link Rd, Bangalore 560099, India. The dry powder was equilibrated with 0.1 M phosphate buffer (pH 7.4) in a glass vial at 25 °C (water bath), shaking for 24 h. After filtration using a 0.45 μm PVDF membrane filter, the concentration of 79 was determined by HPLC, comparing the peak area obtained with that from a standard solution (0.86 μM) in 1:1:2 EtOH/water/CH3CN.

Microsomal Stability Assays. Tests on initial compounds 14, 29, 34, 38, and 39 (Table 3) were run by MDS Pharma Services, 22011 30th Drive SE, Bothell, WA 98021-4444, as previously described. Compounds 39, 44, 49, 53, 54, 59, 61, 71, 107, 108, 111-113, and 116 were evaluated by Advinus Therapeutics Ltd., 21 & 22 Phase II, Peenya Industrial Area, Bangalore 560058, India, using a published procedure in which the compound
concentration was 0.5 µM and the incubation time was 30 min. Additional analyses on compounds 28, 44, 59, 62, 71, 79, 87, 90, 91, 93-95, 129, 142, 152, 170, and 178 were performed by WuXi AppTec (Shanghai) Co., Ltd., 288 FuTe ZhongLu, WaiGaoQiao Free Trade Zone, Shanghai 200131, China, via a reported method.11

**Distribution Coefficient and pK<sub>a</sub> Measurements.** The octanol-water partition coefficient (LogP) of 4 at 20 ºC was measured in duplicate by Advinus Therapeutics Ltd., Bangalore, India, using the shake-flask method with HPLC analysis. LogD and pK<sub>a</sub> data for 79 were measured by WuXi AppTec (Shanghai) Co., Ltd. The LogD value was found by assessing the distribution of 79 between 100 mM phosphate buffer of pH 7.4 and octanol at room temperature (final matrix contained 1% DMSO), using the shake-flask method and LC-MS/MS analysis. The pK<sub>a</sub> value was obtained by UV spectroscopy, employing 80% MeOH as the initial cosolvent.

**Plasma Protein Binding Assay.** Studies of 4 and 79 were conducted by WuXi AppTec (Shanghai) Co., Ltd., using equilibrium dialysis across a semi-permeable membrane. Briefly, a 2 µM compound solution in plasma (0.5% DMSO) was dialyzed against 100 mM phosphate buffered saline (pH 7.4) on a rotating plate incubated for 4 or 6 h at 37 ºC. Following precipitation of protein with CH<sub>3</sub>CN, the amount of compound present in each compartment was quantified by LC-MS/MS; values are the mean of triplicate determinations.

**Permeability Assay.** This was performed by WuXi AppTec (Shanghai) Co., Ltd. MDCK-MDR1 cells were seeded onto polyethylene membranes in 96-well plates at 2 x 10<sup>5</sup> cells/cm<sup>2</sup>, giving confluent cell monolayer formation over 4-7 d. A solution of 79 (2 µM in 0.4% DMSO/HBSS buffer) was applied to the apical or basolateral side of the cell monolayer. Permeation of the compound from A to B direction or B to A direction was determined in triplicate over a 150 min incubation at 37 ºC and 5% CO<sub>2</sub> (95% humidity). In addition, the
efflux ratio of 79 was also determined. Test and reference compounds were quantified by LC-MS/MS analysis based on the peak area ratio of analyte/internal standard.

**Ames Test.** Compound 71 (at doses of 1.5, 4, 10, 25, 64, 160, 400, and 1000 µg/well) was evaluated in the Mini-Ames reverse mutation screen conducted by WuXi AppTec (Suzhou) Co., Ltd., 1318 Wuzhong Avenue, Wuzhong District, Suzhou 215104, China. Two *Salmonella* strains (TA98 and TA100) were employed, both in the presence and absence of metabolic activation (rat liver S9). Positive controls (2-aminoanthracene, 2-nitrofluorene and sodium azide) and a negative (DMSO solvent) control were included.

**hERG Assay.** The effects of compounds 44 and 79 on cloned hERG potassium channels expressed in Chinese hamster ovary cells were assessed by WuXi AppTec (Shanghai) Co., Ltd., using the automated patch clamp method. Six concentrations (0.12, 0.37, 1.11, 3.33, 10, and 30 µM) were tested (at room temperature) and at least three replicates were obtained for each.

**CYP3A4 Inhibition Assay.** The study was performed by WuXi AppTec (Shanghai) Co., Ltd. Compound 79 (at concentrations of 1 and 10 µM) was incubated with NADPH-fortified pooled HLM (0.2 mg/mL) and testosterone (50 µM) in phosphate buffer (100 mM) at 37 °C for 10 min. Following quenching with CH₃CN, samples were analysed for the formation of 6β-hydroxytestosterone by LC-MS/MS and the percentage inhibition was determined (ketoconazole was the positive control and tolbutamide was used as an internal standard).

**In Vivo Experiments.** All animal experiments were performed according to institutional ethical guidelines for animal care. Antitubercular efficacy studies in mice were approved by the UIC IACUC (UIC AWA no. A3460-01; ACC application no. 12-183). For VL, mouse model studies (LSHTM) were conducted under license from the UK Home Office (license no. PIL 70/6997), hamster studies at CDRI were approved by the CSIR-CDRI animal ethics
committee (license no. 19/2009/PARA/IAEC), and hamster studies at LMPH were approved by the ethical committee of the University of Antwerp (UA-ECD 2010-17).

**Acute TB Infection Assay.** Each compound (including 6, which was employed as an internal reference standard) was administered orally to a group of 7 *M. tb*-infected BALB/c mice at 100 mg/kg daily for 5 days a week for 3 weeks, beginning on day 11 postinfection, in accordance with published protocols. The results were typically recorded as the ratio of the average reduction in colony forming units (CFUs) in the compound-treated mice/the average CFU reduction in the mice treated with 6.

**Acute VL Infection Assay (Mouse Model, LSHTM).** Test compounds were orally dosed once per day for 5 days consecutively to groups of 5 female BALB/c mice infected with 2 x 10⁷ *L. donovani* amastigotes, with treatment commencing one week postinfection, as described. Miltefosine (1) and AmBisome were positive controls, and parasite burdens were determined from impression smears of liver sections. Efficacy was expressed as the mean percentage reduction in parasite load for treated mice in comparison to untreated (vehicle-only) controls.

**Chronic VL Infection Assay 1 (Hamster Model, CDRI).** Golden hamsters (weighing 40-45 g) were infected intracardially with 1 x 10⁷ *L. donovani* amastigotes, and then, 15 days later, all animals were subjected to splenic biopsy to assess the level of infection. Groups of hamsters having an appropriate infection grading (5-15 amastigotes/100 spleen cell nuclei) were treated with test compounds, starting on day 17 and dosing orally once per day for 5 days, according to the usual procedure. Post-treatment splenic biopsies taken 12 days after the first dose were employed to determine the intensity of infection, as previously reported.

**Chronic VL Infection Assay 2 (Hamster Model, LMPH).** Golden hamsters (weighing 75-80 g) were infected with 2 x 10⁷ *L. infantum* amastigotes, and 21 days post-infection, treatment groups of 6 animals each were dosed orally once or twice per day with test
compounds (formulated in PEG-400) for 5 days consecutively. Parasite burdens in three target organs (liver, spleen, and bone marrow) were determined by microscopic evaluation of impression smears (stained with Giemsa), and efficacy was expressed as the mean percentage load reduction for treated hamsters in comparison to untreated (vehicle-only) controls. Miltefosine (I) was included as a reference drug in all experiments.

**Mouse Pharmacokinetics.** Compound 28 was evaluated by UNT Health Science Center, 3500 Camp Bowie Boulevard, Fort Worth, TX 76107-2699 (using a method approved by the UNTHSC IACUC; AWA no. A3711-01). Following oral administration to female BALB/c mice at 40 mg/kg as a suspension in 0.5% carboxymethylcellulose/water, blood samples were collected (at time intervals of 0.5, 1, 1.5, 2, 4, 6, 8, and 24 h), centrifuged, and analyzed by LC-MS/MS to generate the required PK parameters. Compound 34 was assessed by MDS Pharma Services, 22002 26th Avenue SE, Suite 104, Bothell, WA 98021-4444, via a similar procedure (but employing mixed gender CD-1 mice and an oral formulation of 0.5% carboxymethylcellulose and 0.08% Tween 80 in water). Studies of compounds 39, 44, 49, 53, 54, and 112 were conducted by Advinus Therapeutics Ltd., 21 and 22 Phase II, Peenya Industrial Area, Bangalore 560058, India, according to a published protocol. Briefly, compounds were administered to groups of male Swiss Albino mice; intravenous dosing (at 1 mg/kg) employed a solution vehicle comprising 20% NMP and 40% PEG-400 in 100mM citrate buffer, pH 3, while oral dosing (at 25 mg/kg) was as a suspension in 0.5% carboxymethylcellulose and 0.08% Tween 80 in water (except for 112, where the iv solution was 10% NMP, 10% cremophor EL and 10% propylene glycol in saline, and oral dosing at 12.5 mg/kg was as a suspension in 7% Tween 80 and 3% EtOH in water). Samples derived from plasma (at 0.083 for iv only, 0.25, 0.5, 1, 2, 4, 6, 8, 10, 24 and 48 h) were centrifuged prior to analysis by LC-MS/MS and the PK parameters were determined using WinNonlin software (version 5.2). Finally, 71 was examined by WuXi AppTec (Shanghai) Co., Ltd.; in
this case, oral dosing of female BALB/c mice was at 25 mg/kg in PEG-400 (sampling at 0.25, 1, 2, 4, 8, and 24 h), and the PK data were derived following similar LC-MS/MS analysis.

Rat and Hamster Pharmacokinetics. Compounds 71, 79, and 87 were assessed in male Sprague-Dawley rats and female Golden Syrian hamsters by WuXi AppTec (Shanghai) Co., Ltd. Intravenous dosing (at 1 mg/kg for rats and 2 mg/kg for hamsters) utilised a solution formulation of 20% NMP and 40% PEG-400 in citrate buffer, pH 3. In rats, oral dosing (at 5 mg/kg) was as a suspension in 0.08% Tween 80 and 0.5% carboxymethylcellulose in water, whereas PEG-400 was the vehicle employed for oral dosing in hamsters (at 12.5 mg/kg). Plasma samples (at 0.083 for iv only, 0.25, 0.5, 1, 2, 4, 8, and 24 h) were analysed by LC-MS/MS and the PK parameters were calculated using WinNonlin software (version 6.3).

ASSOCIATED CONTENT
Supporting Information
Additional biological assay data, synthetic schemes, graphs of PK and assay data, experimental procedures and characterizations for compounds, combustion analytical data, and representative NMR spectra (PDF); molecular formula strings spreadsheet (CSV).

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ABBREVIATIONS USED

VL, visceral leishmaniasis; TB, tuberculosis; MEK, methyl ethyl ketone (2-butanone); L. don, Leishmania donovani; L. inf, Leishmania infantum; T. cruzi, Trypanosoma cruzi; T. brucei, Trypanosoma brucei; rac, racemic; MLM, mouse liver microsomes; PK, pharmacokinetic; PPB, plasma protein binding; PD, pharmacodynamic; M. tb, Mycobacterium tuberculosis; HRFABMS, high resolution fast atom bombardment mass spectrometry; HRESIMS, high resolution electrospray ionization mass spectrometry; APCI MS, atmospheric pressure chemical ionization mass spectrometry; HLM, human liver microsomes; CFU, colony forming unit; SD, standard deviation.

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Table 1. *In vitro* antiparasitic and antitubercular activities and calculated lipophilicities of 7-substituted 2-nitroimidazooxazines

| compd | Fm | X | aza | R    | CLogP | IC$_{50}^{a,b}$ (µM) | MIC$_{c,b}$ (µM) |
|-------|----|---|-----|------|-------|----------------------|-----------------|
| A     |    |   | 2   | 3'   | 4    |                      |                 |
| B     |    |   | 2'  | 3'   | 6    |                      |                 |
| C     |    |   |      |      |      |                      |                 |
| D     |    |   |      | 5'   |      |                      |                 |
| E     |    |   |      | 2'   | 3'   |                      |                 |

| 4a   |    |   | 2   | 3'   | 4    | 3.47                 | 0.03 0.17 2.6 >64 0.046 5.9 |
| 14   | A  | H | 4-OCF$_3$ | 3.30 | 0.03 0.12 1.2 >64 1.0 7.5 |
| 21   | A  | Me| 4-OCF$_3$ | 3.68 | 0.31 0.30 0.75 >64 0.55 3.3 |
| 22   | A  | H | 4-OBn    | 3.55 | 0.05 0.05 0.05 >64 0.46 3.0 |
| 23   | A  | Me| 4-OBn    | 3.93 | 0.28 0.28 0.28 >64 0.20 1.4 |
| 25   | B  | H | 4-F      | 4.21 | 0.02 0.17 0.53 >64 0.08 1.3 |
| 27   | B  | Me| 4-F      | 4.59 | 0.22 1.8 0.84 >64 0.085 0.61 |
| 28   | B  | H | 4-OCF$_3$ | 5.14 | 0.19 0.40 2.1 >64 0.055 1.5 |
| 29   | B  | Me| 4-OCF$_3$ | 5.52 | 1.1 1.1 0.54 >64 0.093 1.4 |
| 34   | B$^e$ | Me| 4-OCF$_3$ | 5.52 | 0.24 1.3 0.57 >64 0.063 1.1 |
| 38   | B$^f$ | Me| 4-OCF$_3$ | 5.52 | 1.3 1.3 0.77 >64 0.74 6.8 |
| 39   | C  | H | 4-OCF$_3$ | 3.37 | 0.04 0.047 0.061 >64 5.2 4.7 |
| 44   | C  | Me| 4-OCF$_3$ | 3.75 | 0.10 0.13 0.14 >64 0.94 6.8 |
| 45   | C  | H | 4-OBn    | 3.62 | 0.02 0.02 >128 >128 |
| 47   | C  | Me| 4-OBn    | 4.00 | 0.12 >128 >128 |
| 49   | D  | H | 4-F      | 4.11 | 0.01 0.47 0.063 >64 0.18 >128 |
| 52   | D  | Me| 4-F      | 4.49 | 0.20 0.34 0.35 >64 0.085 1.4 |
|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|
| 53 | D | H | 4-OCF$_3$ | 5.03 | 0.06 | 0.28 | 0.24 | >64 | 0.08 | 0.73 |
| 54 | D | Me | 4-OCF$_3$ | 5.41 | 0.52 | 0.36 | 0.72 | >64 | 0.11 | 1.3 |

*Phenylpyridines*

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|
| 55 | D | H | 3 | 4-F | 2.94 | >10 | 0.083 | 0.027 | >64 | 0.24 | 3.5 |
| 56 | D | Me | 3 | 4-F | 3.32 | 0.12 | 0.16 | 0.30 | >64 | 0.29 | 2.7 |
| 59 | D | H | 2’ | 4-F | 3.66 | 0.01 | 0.050 | 0.027 | >64 | 0.025 | <0.25 |
| 61 | D | Me | 2’ | 4-F | 4.04 | 0.09 | 0.097 | 0.23 | >64 | 0.17 | 1.0 |
| 62 | D | H | 2’ | 2,4-diF | 3.65 | 0.07 | 0.037 | 0.030 | >64 | 0.10 | 2.4 |
| 63 | D | Me | 2’ | 2,4-diF | 4.03 | 0.11 | 0.21 | >64 | 0.089 | 2.5 |
| 64 | D | H | 2’ | 4-OCF$_3$ | 4.58 | 0.05 | 0.35 | 0.12 | >64 | 0.027 | 0.47 |
| 65 | D | Me | 2’ | 4-OCF$_3$ | 4.96 | 0.26 | 3.8 | 1.0 | >64 | 0.13 | 5.3 |
| 71 | D | H | 3’ | 4-F | 3.03 | 0.06 | 0.093 | 0.27 | >64 | 0.23 | 2.4 |
| 79 | D$^e$ | H | 3’ | 4-F | 3.03 | (0.03)$^g$ | 0.080 | 0.35 | >64 | 0.11 | 3.2 |
| 87 | D$^f$ | H | 3’ | 4-F | 3.03 | (0.08)$^g$ | 0.22 | 0.29 | >64 | 1.1 | 3.9 |
| 90 | D | Me | 3’ | 4-F | 3.41 | 0.65 | 0.59 | 0.26 | >64 | 0.35 | 3.9 |
| 91 | D | H | 3’ | 2,4-diF | 3.03 | 0.02 | 0.030 | 0.13 | >64 | 0.36 | 8.9 |
| 92 | D | Me | 3’ | 2,4-diF | 3.41 | 0.31 | 0.17 | 0.27 | >64 | 0.40 | 4.9 |
| 93 | D | H | 3’ | 4-OCF$_3$ | 3.96 | 0.05 | 0.12 | 0.17 | >64 | 0.032 | 0.86 |
| 94 | D$^g$ | H | 3’ | 4-OCF$_3$ | 3.96 | 0.11 | 0.26 | >64 | 0.024 | 1.5 |
| 95 | D$^f$ | H | 3’ | 4-OCF$_3$ | 3.96 | 0.13 | 0.13 | >64 | 0.34 | 1.6 |
| 96 | D | Me | 3’ | 4-OCF$_3$ | 4.34 | 0.65 | 4.0 | 0.25 | >64 | 0.05 | 0.88 |
| 99 | E | H | 2’ | 4-F | 3.55 | 0.31 | 0.14 | 0.16 | 59 | 1.7 | 3.0 |
| 101 | E | Me | 2’ | 4-F | 3.93 | 0.18 | 0.35 | >64 | 0.94 | 5.0 |
| 102 | E | H | 2’ | 2,4-diF | 3.55 | 0.25 | 4.0 | 0.23 | >64 | >128 | >128 |
| 103 | E | Me | 2’ | 2,4-diF | 3.93 | 0.24 | 0.22 | >64 | 0.69 | 4.8 |

*Bipyridines*

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|
| 105 | D | H | 2’,2 | 4-F | 2.55 | 0.06 | 50 | 0.34 | >64 | 0.15 | 11 |
| 106 | D | Me | 2’,2 | 4-F | 2.93 | 0.15 | 0.34 | 0.25 | >64 | 0.40 | 9.5 |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 107 | D | H | 2',3 | 4-F | 2.49 | 0.27 | 47 | 0.54 | >64 | 0.074 | 15 |
| 108 | D | Me | 2',3 | 4-F | 2.87 | 0.22 | 0.40 | 0.82 | >64 | 1.9 | 6.2 |
| 109 | D | H | 2',3 | 2,4-diF | 2.60 | >10 | 0.19 | 0.29 | >64 | 0.25 | 4.2 |
| 110 | D | Me | 2',3 | 2,4-diF | 2.98 | 0.20 | 0.43 | >64 | 1.0 | 6.6 |
| 111 | D | H | 2',3 | 4-CF₃ | 2.89 | 0.13 | 2.5 | 0.68 | >64 | 0.09 | 2.5 |
| 112 | D | H | 3',3 | 4-F | 1.87 | 0.09 | >64 | 0.55 | >64 | 2.3 | 21 |
| 113 | D | Me | 3',3 | 4-F | 2.25 | 0.09 | 0.67 | 0.57 | >64 | 2.7 | 43 |
| 114 | D | H | 3',3 | 2,4-diF | 1.98 | 0.08 | 52 | 0.35 | >64 | 1.2 | 41 |
| 115 | D | Me | 3',3 | 2,4-diF | 2.36 | 0.11 | 0.28 | 0.38 | >64 | 0.94 | 18 |
| 116 | D | H | 3',3 | 4-CF₃ | 2.61 | 0.07 | 7.3 | 0.46 | >64 | 0.12 | 58 |
| 117 | E | H | 2',3 | 4-F | 2.38 | >10 | 44 | 0.13 | 35 | >128 | >128 |
| 118 | E | Me | 2',3 | 4-F | 2.76 | 1.1 | 0.52 | >64 | 11 | 7.8 |
| 119 | E | H | 2',3 | 2,4-diF | 2.50 | 0.25 | 6.7 | 0.13 | >64 | 4.3 | 10 |
| 120 | E | Me | 2',3 | 2,4-diF | 2.88 | 0.59 | 0.49 | >64 | 9.3 | 7.9 |

*Other heterobiaryls*

|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 123 | D | H | 2',3’ | 4-F | 2.73 | 0.07 | 8.4 | 0.67 | >64 | 0.35 | 23 |
| 126 | D | H | 2',5’ | 4-F | 3.09 | 0.15 | 0.71 | 4.7 | >64 | 0.15 | >128 |
| 129 | D | H | 2',6’ | 4-F | 2.58 | 0.10 | 0.29 | 0.17 | >64 | 0.04 | 1.7 |
| 131 | D | Me | 2',6’ | 4-F | 2.96 | 0.32 | 0.29 | 0.43 | 57 | 0.44 | 6.3 |
| 132 | D | H | 2',6’,3 | 4-F | 1.41 | 0.53 | >64 | 3.3 | >64 | 0.24 | 21 |
| 133 | D | Me | 2',6’,3 | 4-F | 1.79 | 1.3 | 6.1 | 2.9 | >64 | 23 | 54 |
| 139 | D | H | 3’,5’ | 4-F | 2.79 | 0.07 | 0.21 | 0.26 | 62 | 0.27 | 20 |

*IC₅₀ values for inhibition of the growth of* Leishmania donovani *and Leishmania infantum* (in mouse macrophages) and Trypanosoma cruzi (on MRC-5 cells), or for cytotoxicity toward human lung fibroblasts (MRC-5 cells). Each value (except the single test L. don data) is the mean of at least two independent determinations. For complete results (mean ± SD) please refer to the Supporting Information. Minimum inhibitory concentration against *M. tb*, determined under aerobic (MABA) or hypoxic (LORA) conditions. Data from reference 11. *R*-Enantiomer. *S*-Enantiomer. LMPH data (mean of 2 values).
Table 2. *In vitro* antiparasitic and antitubercular activities and calculated lipophilicities of cyclic amine-based analogues

| compd | Fm | X   | CLogP | IC$_{50}^{a,b}$ (µM) | MIC$_{c,b}$ (µM) |
|-------|----|-----|-------|----------------------|-----------------|
|       |     |     |       | L. don  | L. inf  | T. cruzi | MRC-5 | MABA | LORA |
| 142   | A   | H   | 2.16  | 0.19    | 2.3    | 1.7     | >64   | 1.8  | 9.9  |
| 144   | A   | Me  | 2.54  | 0.70    | 0.73   | 1.3     | >64   | 0.34 | 6.8  |
| 147   | B   | H   | 3.36  | 0.88    | 0.87   | 2.9     | >64   | 2.1  | 11   |
| 149   | B   | Me  | 3.74  | 1.0     | 0.32   | 0.87    | >64   | 0.22 | 8.3  |
| 152   | C   | H   | 2.84  | 0.45    | 0.84   | 2.4     | >64   | 2.0  | 22   |
| 154   | C   | Me  | 3.22  | 0.22    | 0.32   | 0.59    | >64   | 0.23 | 48   |
| 157   | D   | H   | 1.17  | 4.8     | 45     | 11      | >64   | 46   | >128 |
| 159   | D   | Me  | 1.55  | 2.8     | 6.5    | 2.8     | >64   | 93   | >128 |
| 160   | E   | H   | 2.42  | >100    | >64    | 1.5     | >64   | 2.5  | 22   |
| 161   | E   | Me  | 2.80  | 0.29    | 0.72   | 3.9     | >64   | 3.4  | 8.4  |
| 170   | F   | H   | 3.50  | 0.24    | 0.22   | >64     | 0.78  | 20   |      |
| 178   | F   | Me  | 3.88  | 0.35    | 0.51   | >64     | 0.37  | 19   |      |

*IC$_{50}$ values for inhibition of the growth of *Leishmania donovani* and *Leishmania infantum* (in mouse macrophages) and *Trypanosoma cruzi* (on MRC-5 cells), or for cytotoxicity toward human lung fibroblasts (MRC-5 cells). Each value (except the single test *L. don* data) is the mean of at least two independent determinations. For complete results (mean ± SD) please refer to the Supporting Information. Minimum inhibitory concentration against *M. tb*, determined under aerobic (MABA)$^{41}$ or hypoxic (LORA)$^{56}$ conditions.
Table 3. Aqueous solubility, microsomal stability, and *in vivo* antileishmanial efficacy data for selected analogues

| compd | pH 7 | pH 1 | aq solubility<sup>a</sup> (µg/mL) | microsomal stability<sup>b</sup> [% remaining at 1 (0.5) h] | *in vivo* efficacy against *L. don* (mouse) [% inhibition at dose in mg/kg]<sup>c</sup> |
|-------|------|------|-----------------------------------|-------------------------------------------------|-----------------------------------------------|
| 4     | 2.4  | (92) | (89) 18 (54)                      | >99                                             | >99 83 49                                     |
| 14    | 4.8  | 57   | 10                                |                                                 |                                               |
| 28    | 0.058| 73   | 75 46 49                         |                                                 |                                               |
| 29    | 0.39 | 85   | 77                                |                                                 |                                               |
| 34    | 86   | 79   |                                   |                                                 |                                               |
| 38    | 86   | 59   |                                   |                                                 |                                               |
| 39    | 4.0  | 85 (96) 57 (70) 23                   | 87                                              |                                               |
| 44    | 2.3  | 58 (86) 50 (61) 2.1 (16)              | 100 100 83 25                                   |                                               |
| 49    | 0.055| (88) 75 45                          | >99                                             |                                               |
| 53    | 0.13 | (97) 94 94                          | 65                                              |                                               |
| 54    | 2.6  | (89) (85) 81                         | 30                                              |                                               |
| 55    | 0.36 |                                  |                                                 |                                               |
| 59    | 0.13 | 2.8 41 43 (60) 12 (16) 67           |                                                 |                                               |
| 61    | 0.69 | 13  (33) (26)                       |                                                 |                                               |
| 62    | 0.13 | 1.5 25 19 2.7                       |                                                 |                                               |
| 71    | 0.32 | 164 44 (63) 14 (52)                  | 100 98 76 59                                   |                                               |
| 79    | 0.45 | 237 58 69 34                         | 93                                              |                                               |
| 87    | 0.47 | 234 63 41 5                          | 85                                              |                                               |
| 90    | 0.19 | 74  50 28 32 41                      |                                                 |                                               |
| 91    | 0.72 | 221 45 31 8.6 91                     |                                                 |                                               |
| 93    | 0.15 | 92  53 41 37 >99                     | >99 97 50                                      |                                               |
| 94    | 0.37 | 110 50 53                           | >99 84                                         |                                               |
| 95    | 0.40 | 141 52 46                           | 52 57                                          |                                               |
|   |  K     |   |   |   |   |
|---|-------|---|---|---|---|
| 99| 0.027 | 0.56| |   |   |
|107| 0.87  |   | (81)| (51)|   |
|108| 4.5   |   | (68)| (39)|   |
|111| 0.36  |   | (72)| (70)|   |
|112| 3.9   |   | (93)| (87)| (70)| 44|
|113| 2.3   |   | (82)| (43)|   |
|116| 0.30  |   | (82)| (81)|   |
|129| 1.8   |   | 61 | 56 | 13 | 85 |
|139| 0.59  |   |   |   |   |
|142| 10    | 14900| 85 | 77 | 15 | 55 |
|152| 49    | 21100| 57 | 58 | 0  |   |
|170| 6.1   | 34300| 33 | 17 | 0.7| 45 |
|178| 2.2   | 9970 | 11 | 1.2| 0.2|   |

*aKinetic solubility (µg/mL) in water (pH 7) or 0.1 M HCl (pH 1) at 20 °C, determined by HPLC (see the Experimental Section, Method A).*  
*bPooled human (H), CD-1 mouse (M), or hamster (Ham) liver microsomes; data in parentheses are the percentage parent compound remaining following a 30 min incubation.*  
*cDosing was orally, once daily for 5 days consecutively; data are the mean percentage reduction of parasite burden in the liver.*  
*dData from reference 11.*
Table 4. Pharmacokinetic parameters for selected compounds in various species

|     | intravenous (1-2 mg/kg)\(^a\) | oral (5-40 mg/kg)\(^b\) |
|-----|-------------------------------|-------------------------|
|     | \(C_0\) (µg/mL) | CL (mL/min/kg) | Vdss (L/kg) | \(t_{1/2}\) (h) | AUC\(_{last}\)\(^b\) (µg·h/mL) | \(C_{max}\) (µg/mL) | \(T_{max}\) (h) | \(t_{1/2}\) (h) | AUC\(_{last}\)\(^b\) (µg·h/mL) | \(F\)^\(c\) (%) |
| compd |     |     |     |     |     |     |     |     |     |     |     |
| Mice |     |     |     |     |     |     |     |     |     |     |     |
| \(Rac-4\)^\(d\) | 0.88 | 9.5 | 1.7 | 2.2 | 1.69 | 4.1 | 4.0 |     |     |     |     |
| 28   |     |     |     |     |     |     |     |     |     |     |     |
| 34   |     |     |     |     |     |     |     |     |     |     |     |
| 39   | 0.36 | 48  | 3.2 | 1.1 | 0.341 | 1.3 | 0.5 |     |     |     |     |
| 44   | 0.79 | 12  | 2.5 | 2.8 | 1.31 | 1.4 | 3.0 |     |     |     |     |
| 49   | 2.9  | 0.52| 0.40| 6.7 | 31.6  | 4.2 | 6.0 |     |     |     |     |
| 53   | 0.66 | 1.3 | 1.9 | 17  | 11.2  | 14  | 8.0 |     |     |     |     |
| 54   | 0.43 | 2.3 | 5.0 | 27  | 5.26  | 0.79| 10  |     |     |     |     |
| 71   |     |     |     |     |     |     | 13  | 4.0 | 3.4 | 112  |     |
| 112  | 14  | 0.70| 0.12| 2.1 | 24.7  | 14  | 2.0 |     |     |     |     |
| Rats |     |     |     |     |     |     |     |     |     |     |     |
| 71   | 1.3 | 3.9 | 0.94| 3.0 | 4.36  | 0.49| 3.3 | 6.7 |     | 4.27  | 22  |
| 79   | 1.5 | 6.3 | 0.86| 1.7 | 2.65  | 0.79| 3.3 | 3.1 |     | 4.08  | 34  |
| 87   | 1.1 | 5.5 | 1.4 | 3.2 | 3.14  | 0.71| 3.3 | 3.7 |     | 5.64  | 41  |
| Hamsters |     |     |     |     |     |     |     |     |     |     |     |
| 71   | 2.5 | 11  | 1.0 | 1.2 | 3.12  | 0.94| 2.7 | 4.7 |     | 4.83  | 26  |
| 79   | 1.4 | 2.0 | 4.2 |     |     |     |     |     | 6.82  |     |
| 87   | 0.73| 2.7 | 10  |     |     |     |     |     | 3.68  |     |

\(^a\)The intravenous dose was 1 mg/kg for mice and rats and 2 mg/kg for hamsters. The oral dose in mice was 25 mg/kg, except for 28 and 34 (40 mg/kg) and 112 (12.5 mg/kg); in other species, the oral doses were 5 mg/kg (rats) or 12.5 mg/kg (hamsters). \(^b\)Area under the curve calculated to the last time point (10, 24, or 48 h). \(^c\)Oral bioavailability, determined using dose normalised AUC\(_{last}\) values. \(^d\)Data for racemic 4 from reference 11. \(^e\)Extrapolated AUC\(_{inf}\) value.
**Table 5.** *In vivo* efficacy data for selected lead compounds in the *L. inf* hamster model

| compd | dose regimen<sup>a</sup> | % inhibition in target organs<sup>b</sup> |
|-------|--------------------------|------------------------------------------|
|       |                          | liver | spleen | bone marrow |
| 1     | 40 mg/kg, q.d.           | 92.6  | 99.5   | 89.0        |
| 4<sup>c</sup> | 25 mg/kg, q.d.       | 100   | 99.9   | 99.7        |
|       | 12.5 mg/kg, q.d.        | 99.0  | 98.7   | 94.0        |
| 44    | 25 mg/kg, b.i.d.         | 92.2  | 91.1   | 82.5        |
|       | 50 mg/kg, q.d.           | 88.6  | 89.5   | 73.0        |
| 71    | 25 mg/kg, b.i.d.         | 99.9  | 99.4   | 99.6        |
|       | 12.5 mg/kg, b.i.d.       | 99.9  | 99.5   | 99.4        |
|       | 6.25 mg/kg, b.i.d.       | 98.0  | 95.7   | 96.3        |
|       | 3.13 mg/kg, b.i.d.       | 68.3  | 69.8   | 64.5        |
|       | 12.5 mg/kg, q.d.         | 95.2  | 87.5   | 92.8        |
| 79    | 12.5 mg/kg, b.i.d.       | 99.5  | 99.4   | 96.8        |
|       | 6.25 mg/kg, b.i.d.       | 91.0  | 91.6   | 73.3        |
| 87    | 12.5 mg/kg, b.i.d.       | 88.2  | 80.8   | 82.3        |
|       | 6.25 mg/kg, b.i.d.       | 53.1  | 46.7   | 35.0        |

<sup>a</sup>All compounds were dosed orally, once or twice daily for 5 days consecutively. <sup>b</sup>Data are the mean percentage reduction of parasite burden in target organs. <sup>c</sup>Data from reference 11.
### Table 6. Additional comparative data for lead compounds 4 and 79

| property                                      | 4       | 79      |
|-----------------------------------------------|---------|---------|
| Molecular weight (Da)                         | 359.3   | 370.3   |
| LogD (measured)                               | 3.10    | 2.45<sup>a</sup> |
| pK<sub>a</sub> (measured)                      |         | 3.95<sup>a</sup> |
| Thermodynamic solubility (µM):                |         |         |
| pH 7.4                                        | 2.8     | 5.4<sup>b</sup> |
| pH 6.5/5.0                                    |         | 3.1/18  |
| Permeability:                                 |         |         |
| P<sub>app</sub> (x10<sup>-6</sup> cm/s) A to B/B to A | 22.6/24.7<sup>c</sup> | 29.2/26.2<sup>d</sup> |
| Human plasma protein binding (%)              | 93.9    | 96.5    |
| Mutagenic effect (Ames test)                   | No      | No<sup>a,e</sup> |
| hERG IC<sub>50</sub> (µM)                     | 10.5    | >30     |
| CYP3A4 IC<sub>50</sub> (µM)                    | >25     | >100    |

<sup>a</sup>For racemate (71).<sup>b</sup>Preclinical batch.<sup>c</sup>Caco-2 data from reference 54.<sup>d</sup>MDCK-MDR1 data; no P-gp mediated efflux.<sup>e</sup>Not mutagenic in strains TA98 and TA100, either in the presence or absence of metabolic activation (S9 fraction).
Figure 1. Structures of antitubercular or antileishmanial agents
Figure 2. Scaffold hopping to 7-substituted 2-nitroimidazooxazines
Figure 3. Comparative *in vivo* efficacy against *L. don* in the mouse model: (a) 50 mg/kg, (b) 25 mg/kg and (c) 6.25 mg/kg
Figure 4. Effect of lipophilicity on potency against *L. inf* for 35 racemic 7-H analogues
**Figure 5.** Comparative *in vivo* efficacy against *L. inf* in the hamster model (LMPH)

| Test compound (dose in mg/kg, b.i.d.) | % Inhibition |
|--------------------------------------|--------------|
| 44 (25)                              | 87 (6.25)    |
| 71 (12.5)                            | 79 (12.5)    |
| 71 (6.25)                            | 79 (6.25)    |
| 71 (12.5)                            | 79 (12.5)    |
| 71 (6.25)                            | 79 (6.25)    |
| 87 (12.5)                            | 87 (6.25)    |

Legend:
- Liver
- Spleen
- Bone marrow
Figure 6. Comparison of 6, 34, and 38 in the acute TB infection mouse model
Scheme 1

Reagents and conditions: (i) Br(CH₂)₂CH=CH₂ or 15, K₂CO₃, DMF, 60-73 °C, 4.5-11 h; (ii) OsO₄, NMO, CH₂Cl₂, 20 °C, 4 h; (iii) TIPSCl, imidazole, DMF, 20 °C, 2-3 d; (iv) NaH, DMF, 0-20 °C, 2.5-7 h; (v) 1% HCl in 95% EtOH, 20 or 44 °C, 1.5-3 d; (vi) ArCH₂Br or 4-BnOBrCl, NaH, DMF, 0-20 °C, 2.5-7 h; (vii) ArB(OH)₂, toluene, EtOH, 2 M Na₂CO₃, Pd(dppf)Cl₂ under N₂, 86-90 °C, 20-75 min; (viii) Ac₂O, pyridine, 20 °C, 38 h; (ix) preparative chiral HPLC (see text); (x) K₂CO₃, aq MeOH, 20 °C, 4 h.
Scheme 2

A

\[
\begin{align*}
\text{O}_2\text{N} & \text{N} \quad \text{O}_2\text{N} \\
13 & \text{OH} \quad \text{OH} \\
\text{compounds} & 39 \text{ and } 45 \\
& \text{of Table 1} \\
& (36-61\%) \\
\end{align*}
\]

B

\[
\begin{align*}
\text{Reagents for step iii:} & \\
\text{15} & \\
\end{align*}
\]

\[
\begin{align*}
\text{O}_2\text{N} & \text{N} \quad \text{O}_2\text{N} \\
40 & \text{Cl} \quad \text{Cl} \\
\text{41} & \text{(84\%)} \\
\text{42} & \text{(85\%)} \\
\text{43: } R=\text{OCO}_2\text{F} & \text{(77\%)} \\
\text{444: } R=\text{OBn} & \text{(79\%)} \\
\text{compounds} & 44 \text{ and } 47 \\
& \text{of Table 1} \\
& (54-61\%) \\
\end{align*}
\]

C

\[
\begin{align*}
\text{compounds} & 58, 62, 64, 99, 102, 105, 107, \\
& 109, 111, 117 \text{ and } 119 \\
& \text{of Table 1} \\
& (8-93\%) \\
\end{align*}
\]

Reagents and conditions: (i) ArOH, DEAD, PPh₃, THF, 0-20 °C, 15-51 h; (ii) ArB(OH)₂, DMF, (toluene, EtOH), 2 M Na₂CO₃ or 2 M KHCO₃, Pd(dppf)Cl₂ under N₂, 70-91 °C, 1.5-5 h; (iii) 15, K₂CO₃, DMF, 73 °C, 14 h; (iv) m-CPBA, Na₂HPO₄, CH₂Cl₂, 0-20 °C, 18 h; (v) ArOH, K₂CO₃, MEK, 82-83 °C, 8-10 h; (vi) NaH, DMF, 0-20 °C, 2-2.5 h; (vii) 57 or 97, NaH, DMF, 0-20 °C, 2.3-3 h; (viii) bis(pinacolato)diboron, KOAc, DMF, Pd(dppf)Cl₂ under N₂, 84-90 °C, 3.5 h, then 104, 2 M Na₂CO₃, Pd(dppf)Cl₂ under N₂, 85-90 °C, 2.5-3.5 h.
Scheme 3 

A

\[
\begin{align*}
\text{O}_2\text{N-} & \text{N-} \text{Cl} \quad \text{i} \rightarrow \quad \text{O}_2\text{N-} & \text{N-} \text{Cl} \\
40 & \quad \rightarrow & \quad 66 \ (88\%) \\
\text{Reagent for step iii:} & \quad 68 \quad \text{HO-} \text{N-} \text{Br}
\end{align*}
\]

B

\[
\begin{align*}
\text{O}_2\text{N-} & \text{N-} \text{Cl} \quad \text{i} \rightarrow \quad \text{O}_2\text{N-} & \text{N-} \text{Cl} \\
73 \ (74\%) & \quad \rightarrow & \quad 74: \text{R}=\text{H} \ (98\%) \\
75: \text{R}=\text{Ts} \ (87\%) \\
\text{Reagent for step i:} & \quad 72 \quad \text{O-} \text{O-} \text{O}
\end{align*}
\]

C

\[
\begin{align*}
\text{O}_2\text{N-} & \text{N-} \text{Cl} \quad \text{i} \rightarrow \quad \text{O}_2\text{N-} & \text{N-} \text{Cl} \\
81 \ (75\%) & \quad \rightarrow & \quad 82: \text{R}=\text{H} \ (88\%) \\
83: \text{R}=\text{Ts} \ (87\%) \\
\text{Reagent for step i:} & \quad 80 \quad \text{O-} \text{O-} \text{O}
\end{align*}
\]

D

\[
\begin{align*}
\text{O}_2\text{N-} & \text{N-} \text{Cl} \quad \text{i} \rightarrow \quad \text{O}_2\text{N-} & \text{N-} \text{Cl} \\
42 & \quad \rightarrow & \quad 88 \ (70\%) \\
\text{Reagent for step iii:} & \quad 88 \quad \text{OH-} \text{N-} \text{Br}
\end{align*}
\]

\[
\begin{align*}
\text{O}_2\text{N-} & \text{N-} \text{Cl} \quad \text{i} \rightarrow \quad \text{O}_2\text{N-} & \text{N-} \text{Cl} \\
88 \ (70\%) & \quad \rightarrow & \quad 89 \ (66\%) \\
\text{Reagent for step iv:} & \quad 89 \quad \text{O-} \text{O-} \text{O-} \text{Br}
\end{align*}
\]

\[\text{Compounds 71, 91, 93, 112, 114 and 116 of Table 1 (67-93\%)}\]

\[\text{Compounds 79 and 94 of Table 1 (85-87\%)}\]

\[\text{Compounds 87 and 95 of Table 1 (86-89\%)}\]

\[\text{Compounds 90, 92, 96, 113 and 115 of Table 1 (61-88\%)}\]

\[\text{Reagents and conditions: (i) Br(CH}_2)_2\text{CH}=\text{CH}_2 \text{ or 72 or 80, K}_2\text{CO}_3, \text{DMF, 70-74 °C, 19-72 h; (ii) m-CPBA, CH}_2\text{Cl}_2, 0-20 °C, 34 h; (iii) 68, K}_2\text{CO}_3, \text{MEK, 81-84 °C, 19-42 h; (iv) NaH, DMF, 0-20 °C, 2.5-3.5 h; (v) ArB(OH)}_2, \text{DMF, (toluene, EtOH), 2 M Na}_2\text{CO}_3 \text{ or 2 M KHCO}_3, \text{Pd(dppf)Cl}_2 \text{ under N}_2, 70-90 °C, 2-4 h; (vi) 1 M HCl, MeOH, 0-20 °C, 6 h; (vii) TsCl, pyridine, -10 to 20 °C, 13-15 h; (viii) DBU, CH}_2\text{Cl}_2, 0-20 °C, 8-9 h.}\]
Scheme 4

A

Reagents for step i: Br\(\text{N} = \text{N}\) Br\(\text{N} = \text{N}\) Br\(\text{N} = \text{N}\) Br

(i) 121 or 124 or 127, NaH, DMF, 0-20 °C, 2.5-3 h; (ii) ArB(OH)\(_2\), DMF, toluene, EtOH, 2 M Na\(_2\)CO\(_3\) or 2 M KHCO\(_3\), Pd(dppf)Cl\(_2\) under N\(_2\), 80-90 °C, 2.3-3.5 h; (iii) EtOCH\(_2\)Cl, K\(_2\)CO\(_3\), DMF, 20 °C, 16 h; (iv) 1.25 M HCl in MeOH, 53 °C, 4 h; (v) 137, K\(_2\)CO\(_3\), MEK, 83 °C, 24 h; (vi) NaH, DMF, 0-20 °C, 3 h.
Reagents and conditions: (i) amine (140, 145, 150, or 155), MEK (or DME), 70-85 °C, 16-84 h; (ii) NaH, DMF, 40-60 °C or 0-20 °C (for 170) or 20-39 °C (for 178), 1.5-5 h; (iii) triphosgene, Et$_3$N, THF, 20 °C, 30 min, then 140, THF, 20 °C, 2 h; (iv) 163, NaH, DMF, 70 °C, 14-28 h; (v) TBSOTf, 2,6-lutidine, CH$_2$Cl$_2$, 0-20 °C, 1-2.5 d; (vi) H$_2$ (60 psi), 10% Pd-C, EtOH, EtOAc, 20 °C, 45-51 h; (vii) I$_2$, PPh$_3$, imidazole, CH$_2$Cl$_2$, 20 °C, 17-19 h; (viii) 2-chloro-4-nitroimidazole, K$_2$CO$_3$, DMF, 63-75 °C, 70-72 h; (ix) TBAF, THF, 20 °C, 5-25 h.
Table of Contents graphic

[Diagram of chemical structures involving OXAZOLE and OXAZINE compounds with notation for new class and side chain optimisation]

71: R=F (VL lead)
93: R=OCF₃ (dual VL/TB lead)