Highly diastereoselective approach to methylenecyclopropanes via boron-homologation/allylboration sequences†

A. N. Baumann, A. Music, K. Karaghiosoff and D. Didier*

A simple and efficient diastereoselective synthesis of methylenecyclopropanes is described, in which boron-homologation and allylboration are merged into a one-pot process, starting from in situ generated cyclopropenyllithium species. This unprecedented methodology opens a new route to strained allylideneacyclalkanes containing a quaternary stereocenter, in high yields and excellent diastereomeric ratios.

Allylideneacyclalkanes (ACPs) possess a fascinating reactivity which continues to spark curiosity among the organic chemistry community, as they are candidates for a wide range of transformations. These structures have been recently employed to undergo ring expansion reactions in the presence of Lewis acids, or in acyclic stereocontrol through hydrometallations or zirconium-promoted C–C bond cleavage. Besides, ACPs represent valuable precursors of chiral cyclopropanes, architectures that can be found in a number of biologically active substrates.

Among different diastereoselective routes for their preparation, Marek and Fox independently developed an easy and straightforward access to ACPs by using cyclopropenylcarbinol derivatives in a $S_N^{2\circ}$ reaction (Scheme 1). Cossey recently demonstrated the potential of secondary cyclopropenylcarbinol to undergo an Ireland–Claisen rearrangement, leading to ACPs by C–C bond formation. [3,3]-Sigmatropic rearrangements have also proven their efficiency in C–O and C–N bond forming reactions, resulting in heterosubstituted ACPs in high diastereoisomeric ratios.

We hypothesized that a thoroughly designed allylic system embedded in the cyclopropyl core could allow for a nucleophilic allylation to proceed. Having recently reported the diastereoselective one-pot synthesis of methylenecyclobutanes using allylboronate derivatives, we envisioned that an easily prepared cyclopropenylmethyl boronic ester (CMB) would undergo the corresponding stereoselective allylboration reaction leading to the formation of challenging methylenecyclopropanes (MCPs) (Scheme 2).

As CMBs (3) were identified as key intermediates in this study, their synthesis was undertaken first. Performing a double lithium-bromide permutation on a tribromocyclopropane afforded the intermediate cyclopropenyllithium species $A$. Subsequent addition of iodomethylboronic ester resulted in a boron-homologation through a 1,2-metallate rearrangement, and derivatives 3a–c were isolated in 58–70%.

With new allylic systems in hands, we investigated allylborations of aldehydes by first using the methyl derivative 3a. Interestingly, the

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With new allylic systems in hands, we investigated allylborations of aldehydes by first using the methyl derivative 3a. Interestingly, the
reaction with benzaldehyde was completed within 15 min, leading
to the expected methylenecyclopropane 4a in 76% yield and
elegant diastereoselectivity (dr > 97:3). Such a fast reaction
time can be explained by strain release when displacing the
double bond from the endo to the exo position.16 As a matter
of fact, similar results were obtained for the synthesis of
methylenecyclobutanes from cyclobutenylmethyl-boronic esters,
with reaction times below 10 min.12 Reaction with aromatic
and heteroaromatic aldehydes furnished the expected products in
high yields (up to 89%) and excellent diastereoselectivities in all
cases (dr > 97:3), as depicted in Scheme 3. Starting from 3a,
methylenecyclopropanes 4a–j were isolated with up to 89%. Slightly
lower yields were obtained in cases of pyrrole and indole derivatives
(4g, 58% and 4e, 52% respectively). An α,β-unsaturated aldehyde
furnished the desired product 4d in good yield and excellent
diastereoisomeric ratio.17

Changing the substituent at the vinylic position of the
starting CMB to a pentyl chain (3b) did not affect the reactivity
of the system nor the stereoselectivity of the allylation, and 4k
was isolated in 66% yield after reaction with biphenylcarbox-
aldehyde. Allylboration was further performed by employing
the silylated substrate 3c. With similarly high diastereomeric
ratios, the introduction of nitrogen- or sulfur-containing hetero-
aromatic and aliphatic aldehydes resulted in building blocks of
higher functionality (4l–p) in good to excellent yields (up to
85%) in only 15 min (Scheme 3).

To further expand the scope, CMB 3d bearing two methyl
substituents was synthesized from the corresponding tribromo-
cyclopropane.14 However, a notable difference of reactivity was
observed when comparing to the previous systems 3a–c, and
acceptable levels of starting material conversion were reached
only after 16 h at room temperature. Despite comparable
strained patterns, the presence of two additional substituents on
3d must play an undeniable role in lowering the reactivity of
the allylic system. Such a sterically hindered moiety could
partially inhibit the approach of the aldehyde, consequently
increasing the reaction time (Scheme 4).

Having successfully demonstrated a new diastereoselective
way of accessing MCPs, we took on the challenge of performing
all the steps in a one-pot process, starting directly from tribromo-
cyclopropanes 1. Addition of two equivalents of n-butyllithium to
leads to the intermediate lithium species A. Subsequent addition
of 2 triggers a 1,2-metallate rearrangement, furnishing CMB B. At
this point, changing the solvent of the reaction from THF to
dichloromethane was detrimental for the reaction to be completed
within 1 hour. THF was found to be competing with the aldehyde
for coordination to the boron atom. Finally, the introduction of
aldehydes allowed for the allylboration to proceed, leading to
MCPs described in Scheme 5. Starting the sequence with 3a
(R1 = Me, entries 1–3) furnished the expected MCPs 4a, 4i and
4j in good yields, while 3c furnished 4n (R1 = (CH2)2TMS, entry 4). In
these cases, the diastereoisomeric ratios continued to be excellent

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Scheme 3 Diastereoselective synthesis of methylenecyclopropanes 4a–p through allylboration of aldehydes from 3a–c.
and the yields were comparable to the step by step procedure. The use of 2-benzothiophene carboxaldehyde in the sequence involving 3a (entry 5) resulted in a full conversion, but a drastic drop of diastereoselectivity was observed.\(^{18}\)

With optimal conditions in hands for the one-pot formation of MCPs, we envisioned that using chiral tribromocyclopropanes (possessing an additional methyl group) could allow for the diastereoccontrolled synthesis of MCPs containing three consecutive stereocenters. Aromatic and aliphatic aldehydes furnished expected “all-syn” adducts 7a–d in excellent yields and stereoselectivities (dr up to 97:3:0:0). The relative configuration of afore mentioned MCPs was attributed by analogy with 7d that could be crystallized and analysed by X-ray diffraction.\(^{19}\)

Next, we investigated the possibility of starting from a chiral cyclopropene 8 (Scheme 6). In this specific case, the lithium species was simply generated by deprotonation of the three-membered ring in the presence of \(n\)-BuLi. The subsequent introduction of 2 under a boron-homologation was then followed by the addition of benzaldehyde, after switching the solvent to dichloromethane. Through an allylboration, the homoallylic alcohol 9 was obtained as a single diastereoisomer, in 58% yield.

Interestingly, low temperatures were not required to observe an excellent diastereochemical outcome. We propose to explain this high diastereoselectivity by a pseudo-chair transition state involving a Zimmerman–Traxler model (Scheme 7). The chain of the aldehyde would then preferentially adopt the pseudo-equtatorial position.\(^{20}\) When starting from chiral CMB 3e possessing a methyl group, one face of the cyclopropenyl derivative is shielded and the aldehyde approaches then from the opposite side, leading to the all-syn relative configuration.

In conclusion, we demonstrated the high potential of boron-homologation and allylboration to promote the simple synthesis of MCPs in excellent diastereoisomeric ratios. A wide variety of aldehydes was used in this unprecedented approach, showing the tolerance of the reaction towards sensitive functional groups. Ultimately, a one-pot process was elaborated, in which boron-homologation and allylboration were merged to simplify the procedure, and leading to MCPs containing up to three consecutive stereocenters.

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Notes and references

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17 When R1 = Ph, a drastic drop of diastereoselectivity was observed (dr = 53:47).

18 Similar results were obtained employing 3a in a step-by-step procedure with 2-benzothiophene carboxaldehyde.

19 CCDC 1439072 (7d).