Stereoselective Carbon–Carbon Bond-Forming Reaction of 1,1-Dibromocyclopropanes via 1-Halocyclopropylzincates

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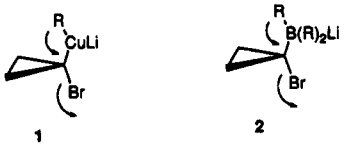
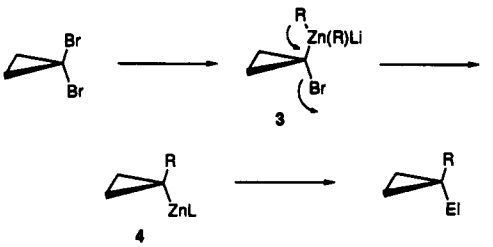
Lithium trialkylzincates react efficiently with 1,1-dibromocyclopropanes **5** to give the corresponding alkylation products **7** nonstereoselectively. The reaction proceeds through a 1,2-alkyl migration of the intermediately formed zincate carbenoid **3** in an invertive manner. Reaction of **5** with BuLi followed by successive treatment of the resulting *trans*-lithium carbenoid **8** with $ZnCl_2$ and an alkyllithium (R^2Li) produces the zincate carbenoid *trans*-**3**, which, in turn, gives *cis*-**7** stereoselectively (Method B). Reaction of lithium trialkylzincates and *trans*-1-bromo-1-chlorocyclopropanes **11** prepared in situ by chlorination of the *trans*-lithium carbenoid with $CF_2ClCFCl_2$ yields *trans*-**7** stereoselectively (Method C). 1-Alkylcyclopropylzinc **4**, an intermediate of the alkylation reaction, reacts smoothly with acyl, aryl, and alkenyl halides in the presence of a palladium(0) catalyst to give the corresponding coupling products **15** and **16**. By generating the cyclopropylzinc intermediate **4** stereoselectively by using method B or C, one can obtain the desired stereoisomers of the coupling products with high selectivity.

Cyclopropane derivatives are valuable synthetic intermediates with considerable utility in the preparation of a variety of cyclic and acyclic organic compounds. *gem*-Dihalocyclopropanes which can be readily prepared by the addition reaction of dihalocarbenes with olefins are one of the most versatile starting materials for the synthesis of substituted cyclopropanes.[1] In this context, much attention has been focused on developing an efficient method for replacing a halogen atom of a dihalocyclopropane in a stereocontrolled manner. Nozaki and Hiyama reported an efficient one-pot dialkylation of *gem*-dibromocyclopropanes where the two bromine atoms are displaced successively with R^1 and R^2 by the reaction with lithium dialkylcuprate ($(R^1)_2CuLi$) and iodoalkane (R^2I), respectively.[2] They proposed a reaction mechanism involving a Br/Cu exchange at the less hindered halogen atom, the consecutive 1,2-alkyl migration reaction of the resulting copper ate carbenoid **1** in a invertive manner, and the second alkylation by R^2I. More recently, Danheiser reported a stereoselective method for the preparation of cyclopropanol derivatives by utilizing a similar 1,2-alkyl migration reaction of a boron ate carbenoid **2**.[3]



The present study was undertaken to develop an efficient and stereoselective route to substituted cyclopropanes by utilizing an 1,2-alkyl migration reaction of the hitherto unknown zincate carbenoid **3**, which would afford the cyclopropylzinc species **4** of a high synthetic potential (Scheme I). Although organozinc compounds are of increasing importance as versatile intermediates in synthetic organic chemistry,[4,5] no attention has been paid to the generation and reaction of cyclopropylzinc species. The present investigation is also devoted to disclose their utility in organic synthesis.[6]

Scheme I



Results and Discussion

Generation and Alkylation Reaction of Lithium 1-Halocyclopropylzincates. 1-Bromocyclopropylzincate **3** can be readily generated by a Br/Zn exchange reaction[7] of dibromocyclopropane **5** with lithium trialkyl-

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(4) (a) Negishi, E.; Okukado, N.; King, A. O.; Van Horn, D. E.; Spiegel, B. I. *J. Am. Chem. Soc.* **1978**, *100*, 2254. (b) Sato, T.; Naruse, K.; Enokiya, M.; Fujisawa, T. *Chem. Lett.* **1981**, 1135. (c) Negishi, E.; Miller, J. A. *J. Am. Chem. Soc.* **1983**, *105*, 6761. (d) Hayashi, T.; Konishi, M.; Kobori, Y.; Kumada, M.; Higuchi, T.; Hirotsu, K. *J. Am. Chem. Soc.* **1984**, *106*, 158. (e) Tamaru, Y.; Ochiai, H.; Nakamura, T.; Tsubaki, K.; Yoshida, Z. *Tetrahedron Lett.* **1985**, *26*, 5559.

(5) (a) Yeh, M. C. P.; Knochel, P. *Tetrahedron Lett.* **1988**, *29*, 2395. (b) Tamaru, Y.; Tanigawa, H.; Yamamoto, T.; Yoshida, Z. *Angew. Chem.* **1989**, *101*, 358. (c) Majid, T. N.; Yeh, M. C. P.; Knochel, P. *Tetrahedron Lett.* **1989**, *30*, 5069. (d) Kitamura, M.; Okada, S.; S. Suga; Noyori, R. *J. Am. Chem. Soc.* **1989**, *111*, 4028. (e) Tucker, C. E.; Rao, S. A.; Knochel, P. *J. Org. Chem.* **1990**, *55*, 5446. (f) Takahashi, T.; Nakazawa, N.; Kanoh, M.; Yamamoto, K. *Tetrahedron Lett.* **1990**, *31*, 7349. (g) Charette, A. B.; Côté, B.; Marcoux, J.-F. *J. Am. Chem. Soc.* **1991**, *113*, 8166. (h) Marek, I.; Normant, J. F. *Tetrahedron Lett.* **1991**, *32*, 5793. (i) Marek, I.; Lefrançois, J.-M.; Normant, J. F. *Tetrahedron Lett.* **1991**, *32*, 5969. (j) Tucker, C. E.; Knochel, P. *J. Am. Chem. Soc.* **1991**, *113*, 9888. (k) AchyuthaRao, S.; Knochel, P. *J. Org. Chem.* **1991**, *56*, 4591. (l) Rao, C. J.; Knochel, P. *J. Org. Chem.* **1991**, *56*, 4593. (m) Srebnik, M. *Tetrahedron Lett.* **1991**, *22*, 2449. (n) Denmark, S. E.; Edwards, J. P. *Synlett* **1992**, 229. (o) Rozema, M. J.; Sidduri, A.; Knochel, P. *J. Org. Chem.* **1992**, *57*, 1956. (p) Waas, J. R.; Sidduri, A.; Knochel, P. *Tetrahedron Lett.* **1992**, *33*, 3717.

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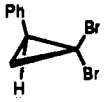
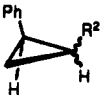
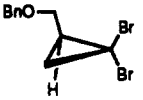
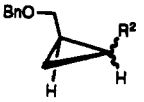
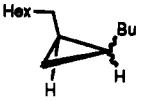
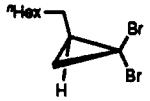
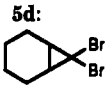
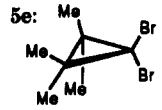
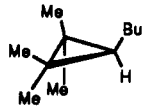
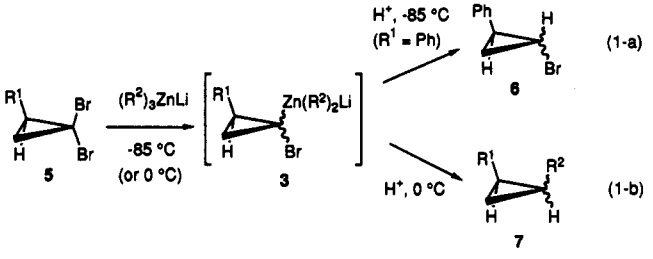
0022-3263/93/1958-2958$04.00/0

Table I. Alkylation Reaction of 1,1-Dibromocyclopropanes via 1-Halocyclopropylzincates

entry	dibromocyclopropane	R^2	method[a]	product	yield[b] (%)	trans:cis[c]
1	**5a**: 	Bu	A	**7a**: R^2 = Bu	88	2.4:1
2			B-1		63	1:33
3			C		60	32:1
4	**5a**	^{t}Bu	B-1	**7b**: R^2 = ^{t}Bu	67	1:6.7
5	**5a**	Et	B-2	**7c**: R^2 = Et	74	1:8.5
6	**5b**: 	Bu	A	**7d**: R^2 = Bu	95	1:2.0
7			B-1		85	1:19
8			C		70	15:1
9	**5b**	^{s}Bu	A	**7e**: R^2 = ^{2}Bu	91	1:1.4
10			B-1		56	1:>10
11			C		63	8.5:1
12	**5b**	^{t}Bu	A	**7f**: R^2 = ^{t}Bu	76	1.1:1
13			B-1		67	1:13
14			C		50	36:1
15	**5b**	Me	A	**7g**: R^2 = Me	78	1:2.0
16			B-1		76	1:8.0
17	**5b**	Et	B-2	**7h**: R^2 = Et	98	1:8.0
18	**5c**:	Bu	A	**7i**: 	94	1:1.6
19			B-1		43	1:5.9
20	**5d**: 	Bu	A	**7j**: 	87[d]	2.6:1[e]
21			B		60[d]	1.2:1[e]
22	**5e**: 	Bu	A	**7k**: 	89	

[a] For methods A, B-1, B-2, and C, see text. [b] Isolated yield unless otherwise noted. [c] Ratios were determined by capillary GC analysis. [d] Yield was determined by GC. [e] Ratio of *exo*-**7j**:*endo*-**7j**.

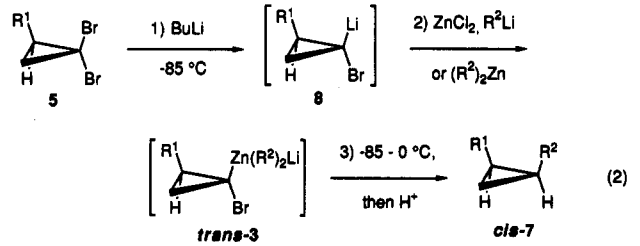
zincate ($(R^2)_3ZnLi$). Thus, treatment of **5a** (R^1 = Ph) with $(Bu)_3ZnLi$ (1.25 equiv) in THF at −85 °C for 1 h followed by the addition of AcOH–THF gave the corresponding bromocyclopropane **6** (trans:cis = 1.8:1) in 82% yield (eq 1a). Carbenoid **3a** (R^1 = Ph) is stable at low temperature.



The reaction for 24 h at −85 °C also gave **6** in high yield (95%, trans:cis = 1.6:1).

Treatment of **5a** with $(Bu)_3ZnLi$ at −85 °C for 1 h followed by warming of the resulting carbenoid **3a** to 0 °C afforded 1-butyl-2-phenylcyclopropane (**7a**) in 86% yield (eq 1b). More conveniently, **7a** was obtained in 95% yield (trans:cis = 1:2.0) by simply performing the reaction at 0 °C. Under these reaction conditions, a variety of dibromocyclopropanes **5a–e** react smoothly with lithium trialkylzincates to give the corresponding alkylation products **7a–k** in high yields (method A in Table I). 1,1-Dichlorocyclopropanes such as 7,7-dichloronorcarane were found to be unreactive. Zincates possessing primary, secondary, and tertiary alkyl ligands all react efficiently. Reaction of $(Ph)_3ZnLi$ was unsuccessful.

The low stereoselectivity observed in the alkylation by method A is improved very much by generating the zincate carbenoid trans-**3** stereoselectively via the corresponding lithium carbenoid **8** (eq 2). Lithium carbenoid **8** can be



generated with high trans selectivity by the reaction of **5** with BuLi in THF at −85 °C.[3,8,9] Successive treatment of **8** with $ZnCl_2$ (1.0 equiv) and R^2Li (2.0 equiv) at −85 °C followed by warming of the resulting zincate carbenoid *trans*-**3** to 0 °C gave *cis*-**7** with high stereoselectivity (method B-1). Alternatively, treatment of lithium car-

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(9) In comparison with the previously reported procedure[3,8] which requires the reaction temperatures of −95 °C or below, the reaction can be performed more conveniently at −85 °C by using a Neslab Cryo Cool immersion cooler.

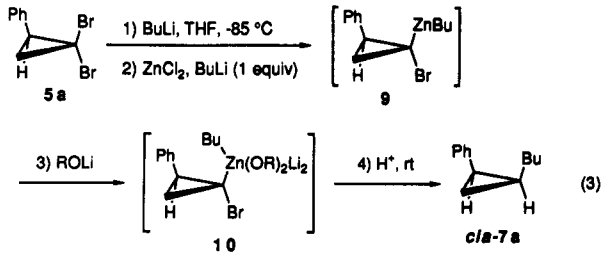
Table II. Stereoselective Alkylation of Dibromocyclopropane 5a by Method B-3

entry	alkoxide	equiv of alkoxide	yield[a] (%) of 7a	trans:cis[b]
1	$PhCH_2OLi$	1.0	11	1:9.6
2	$PhCH_2OLi$	2.0	39	1:38
3	$PhCH_2OLi$	3.0	49	1:43
4	^tBuOK	2.0	18	1:14
5	$LiOCH_2CH_2OLi$	1.0	70	1:10
6	$LiOCH_2CH_2CH_2OLi$	1.0	10	1:11

[a] Isolated yield. [b] Ratios were determined by capillary GC analysis.

benoid 8 with $(Et)_2Zn$ (1.0 equiv) at −85 °C followed by warming up the mixture to 0 °C afforded *cis*-7 (R^2 = Et) stereoselectively (method B-2). By using method B-1 or -2, the cis isomers of a variety of substituted cyclopropanes can be prepared with high selectivity starting from the dibromocyclopropanes **5a-d** (Table I).

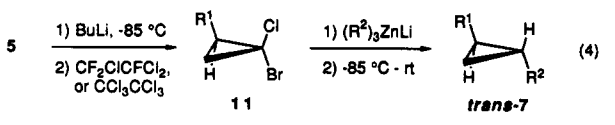
Successive treatment of the lithium carbenoid generated from **5a** with $ZnCl_2$ and 1.0 equiv of BuLi at −85 °C affords zinc carbenoid **9**, which, upon warming to rt, did not undergo alkylation reaction but rearranged[10] to give phenyl-1,2-propadiene. However, in the presence of metal alkoxides, **9** undergoes a similar 1,2-alkyl migration reaction to give *cis*-**7a** stereoselectively (eq 3, Table II).



(3)

The alkylation product was obtained in higher yields by increasing the amount of $PhCH_2OLi$. Addition of the primary alkoxide was more effective than sterically hindered ^tBuOK. The most satisfactory result was obtained when the dilithium alkoxide of ethylene glycol was used. It is known that diorganozinc compounds form tetracoordinate complexes with various neutral ligands.[11] Recently, formation of tetracoordinate hetero zincate of a structure $[Et_2Zn(^tBuO)_2ZnEt_2]^{2-}2K^+$ from Et_2Zn and ^tBuOK was reported.[12] Observation of the efficient alkylation reaction of **9** in the presence of an excess amount of the alkoxides or the bidentate dialkoxides suggests that the 1,2-migration proceeds through the tetracoordinate heterozincate intermediate **10**.

Chlorination of the *trans*-lithium carbenoid generated from **5a** with hexachloroethane or 1,1,2-trichloro-1,2,2-trifluoroethane gave stereoselectively the *trans*-bromochlorocyclopropane **11a** (R^1 = Ph) (trans:cis = >48:1) (eq 4). Metal-exchange reaction of **11a** with $(Bu)_3ZnLi$

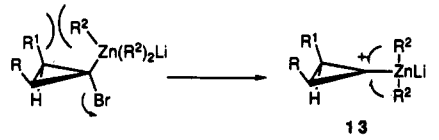


(4)

proceeds exclusively on the bromine atom; the reaction at −85 °C for 16 h gave *cis*-1-chloro-2-phenylcylopropane (**12**) in 72% yield (cis:trans = 46:1). When the reaction was performed at temperatures from −85 °C to rt, *trans*-**7a** (R^1 = Ph, R^2 = Bu) was obtained stereoselectively in 62% yield (trans:cis = 35:1) (eq 4).

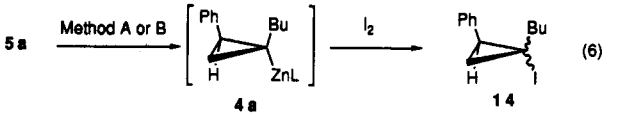
The above reaction sequence can be performed in a single-flask operation without the isolation of the intermediate bromochlorocyclopropanes **11** (method C in Table I). Thus, for example, sucessive treatment of the dibromocyclopropane **5a** with (i) BuLi (1.0 equiv, −85 °C, 15 min), (ii) $CF_2ClCFCl_2$ (1.1 equiv. −85 °C, 30 min), and (iii) $(Bu)_3ZnLi$ (1.25 equiv, −85 °C to rt, 3 h) afforded *trans*-**7a** in 60% yield (trans:cis = 32:1). A wide applicability of method C for the stereoselective preparation of the trans-substituted cyclopropanes is demonstrated by the results summarized in Table I.

Contrasting stereochemical outcomes between the alkylation reactions by using methods B and C demonstrate that the 1,2-alkyl migration of zincate carbenoids **3**[7c,b,13] proceeds in an invertive manner in accord with a stereochemical course reported on the related 1,2-migration of boron[3,14] and copper ate carbenoids.[2] Interestingly, however, a steric effect which affects the stereochemical course was observed especially when the migrating alkyl group (R^2) suffers from considerable steric repulsion. Butylation of dibromonorcarane **5d** by method B-1 gave *exo*- and *endo*-**7j** nonstereoselectively (entry 21) in spite of the stereoselective formation of the *exo*-lithium[8a] and, hence, the *exo*-$Zn(Bu)_2Li$ carbenoid as a intermediate. When the invertive 1,2-migration is sterically hampered, dissociation of the bromide ion appears to precede migration to give the intermediate **13**, which, then, results in nonstereospecific formation of the exo and endo products (eq 5).



(5)

Stereoselective Synthesis of *gem*-Disubstituted Cyclopropanes. Reaction of the dibromocyclopropane **5a** with $(Bu)_3ZnLi$ at 0 °C followed by treatment of the resulting cyclopropylzinc species **4a** with I_2 gave the iodocycloproapane **14** in 94% yield (trans:cis = 1.3:1) (eq 6). Iodination of the cyclopropylizinc **4a** generated



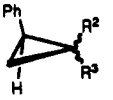
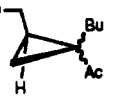
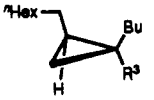
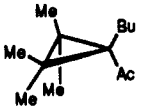
(6)

stereoselectively by method B-1 also proceeded efficiently to give *trans*-**14** with high stereoselectivity (85%, trans:cis = 11:1).

Encouraged by the results showing clean generation of the cyclopropylzinc **4**, we then examined the palladium(0)-catalyzed coupling reaction[4] of **4** with carbon electrophiles. Reaction of the 1-alkylcyclopropylzincs **4** generated

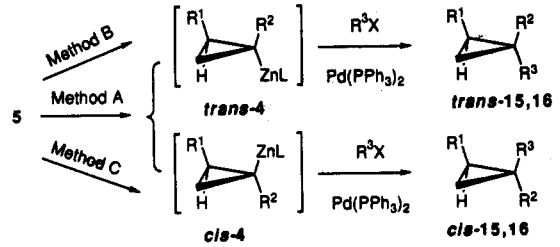
(10) Kirmse, W. *Carbene Chemistry*, 2nd ed.; Academic Press: New York, 1971; p 462.
(11) Nützel, K. *Houben-Wey, Methoden der Organische Chemie*; Müller, E., Ed.; Georg Thieme Verlag: Stuttgart, 1973; Vol. 13/2a, p 658.
(12) Fabicon, R. M.; Prvez, M.; Richey, H. G., Jr. *J. Am. Chem. Soc.* 1991, *113*, 1412.
(13) (a) Negishi, E.; Akiyoshi, K. *J. Am. Chem. Soc.* 1988, *110*, 646. (b) Knochel, P.; Jeong, N.; Rozema, M. J.; Yeh, M. C. P. *Ibid.* 1989, *111*, 6474.
(14) Review: (a) Brown, H. C. *Organic Synthesis via Borans*; Wiley-Interscience: New York, 1975. (b) Negishi, E. *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, F. G. A., Abel, F. W., Eds.; Pergamon Press: Oxford, 1982; Vol. 7, p 255.

Table III. Stereoselective Synthesis of 1-Alkylcyclopropyl Ketones 15

entry	substrate	R^2	electrophile	method	product	yield[a] (%)	trans:cis[b]
1	**5a**	Bu	AcCl	A	**15**: R^2 = Bu, R^3 = Ac	76	1:1.9
2				B-1		74	16:1
3				C		50	1:7.0
4	**5a**	Bu	PhCOCl	A	**15b**: R^2 = Bu, R^3 = PhCO	58	2.1:1
5				B-1		50	38:1
6	**5a**	Bu	EtOCOCl	A	**15c**: R^2 = Bu, R^3 = EtOCO	59	2.5:1
7				B-1		58	60:1
8				C		45	1:28
9	**5a**	Et	AcCl	B-2	**15d**: R^2 = Et, R^3 = Ac	80	7.7:1
10	**5a**	^{s}Bu	AcCl	B-1	**15e**: R^2 = ^{s}Bu, R^3 = Ac	74	*c*
11	**5a**	^{t}Bu	AcCl	B-1	**15f**: R^2 = ^{t}Bu, R^3 = Ac	50	6.7:1
12	**5b**	Bu	AcCl	A	**15g**: 	96	2.4:1
13				B-1		65	5.7:1
14				C		52	1:21
15	**5c**	Bu	AcCl	A	**15h**: R^3 = Ac	70	1.4:1
16				B-1		75	11:1
17				C		66	1:32
18	**5c**	Bu	PhCOCl	A	**15i**: R^3 = PhCO	66	1.4:1
19	**5e**	Bu	AcCl	A	**15j**: 	64	

[a] Isolated yield. [b] Determined by capillary GC analysis. [c] The ratio was not determined.

from **5** by method A with acyl chloride (3.0 equiv) in the presence of $Pd(PPh_3)_2$ (10 mol %) at rt for 16–24 h gave a stereo mixture of cyclopropyl ketone **15** (R^3 = RCO) in high yield (eq 7, method A in Table III). Noteworthy is



(7)

the fact that the coupling reaction proceeds without the loss of stereochemical integrity of **4**. Thus, for example, acetylation of *trans*-**4a** generated by method B-1 gave *trans*-**15a** with high selectivity (entry 2). On the other hand, *cis*-**15a** was obtained stereoselectively in acetylation of *cis*-**4a** generated by method C (entry 3).

Under similar conditions, the cyclopropylzincs **4** underwent cross-coupling reactions with aryl and alkenyl bromides to afford the corresponding *gem*-disubstituted cyclopropanes **16** (Table IV). Here, again, both trans and cis stereoisomers of **16** can be obtained stereoselectively by using methods B and C, respectively.

To our knowledge, this is the first example of palladium(0)-catalyzed coupling reaction of a cyclopropylzinc compound. Our results show a high synthetic potential of this type of organozinc compounds. Efficiency of the catalyzed coupling reaction of the cyclopropylzincs **4** is most typically illustrated in the preparation of the highly hindered ketones **15e,f** (Table III, entries 10 and 11).

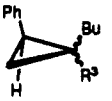
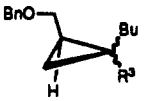
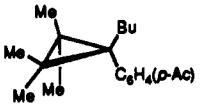
Determination of Stereochemistry. The stereochemistry of the disubstituted cyclopropanes *trans*- and *cis*-**7a-j** were established unequivocally based on the analysis of the coupling constants ($J_{cis} > J_{trans}$) between the cyclopropane ring protons (see Experimental Section).[15]

The configuration of each trisubstituted cyclopropane (*trans*- and *cis*-**15, 16**) was identified by the comparison of the chemical shifts of the ring protons (Figure 1). Due to a shielding effect of the alkyl substituent (R^2)[2,16] and a deshielding effect of the carbonyl group,[15] ring protons of **15** always appear at higher field when they are cis to the R^2 group and, hence, trans to the carbonyl groups. Thus, for a given pair of *trans*- and *cis*-**15**, H_a of the cis isomer resonates at a lower field than does H_a of the trans isomer while the signals due to H_b and H_c of the cis isomer are both centered at a higher field than are the signals due to the corresponding protons of the trans isomer (see Experimental Section). Ring protons of **16** also appear at higher field when they are cis to the butyl group and trans to the aryl or alkenyl group.[15]

The stereochemical assignment is also possible from a long-range *W*-type coupling[16] observed between one of the methylene protons of the R^2 group (H_e) and the ring proton trans to this group (Figure 1). For example, H_b of *trans*-**15b** appears at δ 1.92 as ddd (J_{bc} = 9.2 Hz, J_{ba} = 4.8 Hz, and J_{be} = 1.2 Hz). Decoupling experiments showed that the small coupling is attributed to the interaction with H_e which appears as a m at δ 1.70. On the other hand, the small coupling was observed between H_a (δ 1.06, ddd, J_{ac} = 6.8 Hz, J_{ba} = 5.5 Hz, and J_{ae} = 1.3 Hz) and H_e (δ 2.52, m) of *cis*-**15d**. A similar long-range coupling was also observable for *trans*- and *cis*-**15a,c,d,f** and *trans*-**16a,c**. In these compounds, the R^2 alkyl chain is con-

(15) Gaudner, A. *Stereochemistry*; Kagan, H. B., Ed.; Georg Thieme Verlag: Stuttgart, 1977; Vol. 1, p 77.
(16) Jackman, M. L.; Sternhell, S. *Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, 2nd ed.; Pergamon Press: Oxford, 1969; pp 229 and 334.

Table IV. Stereoselective Synthesis of *gem*-Disubstituted Cyclopropanes 16

entry	substrate	electrophile	method	product	yield[a] (%)	trans:cis[b]
1	1a	PhBr	A	16a: R^3 = Ph	82	1:2.7
2			B-1		60	9.1:1
3			B-3		60	40:1
4			C[c]		68	1:16
5	11a[d]		A		67	1:11
6	1a	CH_2=C(Me)Br	A	16b: R^3 = CH_2=C(Me)	98	1:2.3
7			B-1		76	8.5:1
8			B-3		59	40:1
9			C[c]		45	1:9.2
10	11a[d]		A		63	1:11
11	1a	Me_2C=CHBr	A	16c: R^3 = Me_2C=CH	45	1:1.3
12	5b	PhBr	A	16d: R^3 = Ph	69	1.5:1
13			B-1		44	7.3:1
14			C		42	1:23
15	5b	CH_2=C(Me)Br	A	16e: R^3 = CH_2 = C(Me)	78	2.0:1
16			B-1		70	9.1:1
17			C		47	1:>40
18	5e	*p*-(AcO)C_6H_4Br	A	16f: 	48	

[a] Isolated yield. [b] Determined by capillary GC analysis. [c] Reaction was not performed in one pot; the crude bromochlorocyclopropane obtained by aqueous workup was used without purification in the next step. [d] Trans:cis = 8.0:1.

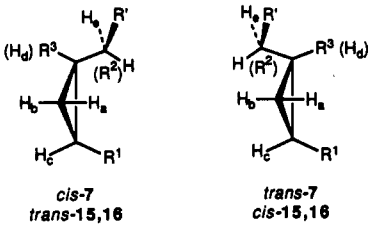


Figure 1.

strained by substitution of the acyl or phenyl group at the geminal position to take an optimal conformation for the *W*-type long-range coupling. No such long-range interaction was observed for the disubstituted cyclopropanes **7**.

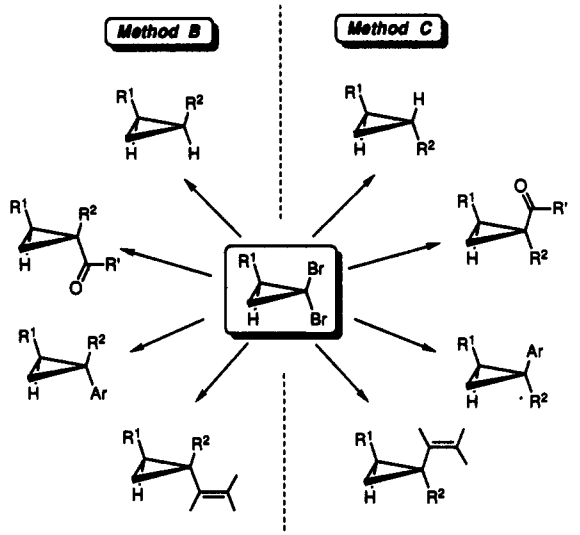
Conclusion

We have developed a highly stereoselective method for preparing a variety of di- and trisubstituted cyclopropanes starting from readily available 1,1-dibromocyclopropanes (Scheme II). It has been demonstrated that the 1,2-alkyl migration reaction of the zincate carbenoids **3** proceeds stereospecifically with inversion of the configuration. By controlling the stereochemistry of the zincate carbenoid **3**, one can obtain the desired stereoisomer of the substituted cylopropanes in a one-pot reaction. Efficiency as well as a promising synthetic potential of the cyclopropylzinc species in palladium-catalyzed cross-coupling reactions has been demonstrated.

Experimental Section

^{1}H NMR spectra of $CDCl_3$ solution were recorded at 200 MHz. GC analyses were performed with 20-m PEG-20M and 30-m OV-1 capillary columns. Wakogel C-300 was used for flash chromatography. Unless otherwise specified, all organic extracts were dried over Na_2SO_4. THF was distilled from sodium benzophenone ketyl. CH_2Cl_2 and DMF were distilled from CaH_2. $ZnCl_2$ was dried over P_2O_5 at 100 °C in vacuo for 10 h. All the reactions were performed under a nitrogen atmosphere. Reactions at −85 °C were performed by using a Neslab Cryo Cool immersion cooler. 1,1-Dibromocylopropanes **5a–e** were prepared by the reaction of the corresponding alkenes with $CHBr_3$ and ^{t}BuOK.[2]

Scheme II



1-Bromo-2-phenylcyclopropane (6).[17] To a suspension of anhydrous $ZnCl_2$ (1.14 mmol) in THF (4.0 mL) at 0 °C was added BuLi (2.12 mL of 1.62 M solution in hexane, 3.43 mmol), and the mixture was stirred for 15 min at this temperature.[18] Dibromocyclopropane **5a** (254 mg, 0.920 mmol) was added to the resulting solution of $(Bu)_3ZnLi$ at −85 °C. The mixture was stirred at −85 °C for 0.5 h before the reaction was quenched with 10% AcOH in THF. The mixture was poured into aqueous HCl (1 N) and was extracted twice with ether. The combined organic layers were washed with aqueous $NaHCO_3$ and dried. Analysis of the mixture by capillary GC (30 m, OV-1) using an internal standard method showed the formation of *trans*- and *cis*-**6** (1.8:1) in 82% yield and the recovery of the starting material (15%). Reaction at −85 °C for 24 h was carried out in a manner similar to that described above.

(17) Kitatani, K.; Hiyama, T.; Nozaki, H. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 3288.

(18) Isobe, M.; Kondo, S.; Nagasawa, N.; Goto, T. *Chem. Lett.* **1977**, 679.

General Procedure for Alkylation of Dibromocyclopropane 5. Method A. To a suspension of anhydrous $ZnCl_2$ (1.0 mmol) in THF (3.5 mL) at 0 °C was added a solution of alkyllithium (3.0 mmol), and the mixture was stirred for 15 min at this temperature. To the resulting solution of the trialkylzincate at 0 °C was added dibromocyclopropane **5** (0.8 mmol). After being stirred for 0.5 h at 0 °C, the mixture was poured into aqueous HCl (1 N) and was extracted twice with ether. The combined organic layers were dried and concentrated in vacuo. The residue was purified by flash chromatography (hexane for **7a–c,i–k** and hexane/ether (98:2) for **7d–h**) to give a mixture of *trans*- and *cis*-**7**. Analytically pure samples were obtained by preparative GC.

Method B-1. To a solution of **6** (1.0 mmol) in THF (3.5 mL) at −85 °C was added BuLi (1.0 mmol, 1.62 M in hexane) during a period of 5 min, and the mixture was stirred for 15 min. To the resulting mixture of lithium carbenoid **8** was added successively a solution of $ZnCl_2$ (1.0 mmol) in THF (1.5 mL) and a solution of alkyllithium (2.1 mmol) at −85 °C. After being stirred for 5 min, the mixture was allowed to warm rapidly to rt by removing the cooling bath and then was stirred further for 0.5 h at rt. By workup and isolation procedures similar to that described in method A, *cis*-**7** was obtained stereoselectively.

Method B-2. To a solution of lithium carbenoid **8** which was prepared from **6** (1.0 mmol) as described in method B-1 at −85 °C was added Et_2Zn (1.1 mmol, 1.0 M in hexane), and the mixture was stirred for 5 min. The mixture was allowed to warm rapidly to rt by removing the cooling bath and was stirred for 0.5 h at rt. By workup and isolation procedures similar to that described in method A, *cis*-**7** was obtained stereoselectively.

Method B-3. To a solution of lithium carbenoid **8** which was prepared from **6** (1.0 mmol) as described in method B-1 at −85 °C was added successively a solution of $ZnCl_2$ (1.1 mmol) in THF (1.5 mL) and BuLi (1.2 mmol, 1.6 M in hexane) at −85 °C, and the mixture was stirred for 15 min at this temperature. To this was then added a suspension of $LiOCH_2CH_2OLi$ (1.1 mmol) in THF (2.8 mL) which was prepared by the reaction of ethylene glycol with BuLi (2 equiv) in THF at 0 °C. The resulting mixture of the heterozincate was allowed to warm rapidly to rt by removing the cooling bath and was stirred for 0.5 h at rt. By workup and isolation procedures similar to that described in method A, *cis*-**7** was obtained stereoselectively.

Method C. To a solution of lithium carbenoid **8** which was prepared from **6** (1.0 mmol) as described in method B-1 at −85 °C was added CF_2ClCC_2F (1.0 mmol), and the mixture was stirred at this temperature for 0.5 h. To this was then added a THF (3.5 mL) solution of the trialkylzincate (1.25 mmol) at −85 °C. The resulting mixture was allowed to warm to rt during a period of 3 h and was stirred for an additional 0.5 h at rt. By a workup procedure similar to that described in method A, *trans*-**7** was obtained stereoselectively.

***trans*-1-Butyl-2-phenylcyclopropane (*trans*-7a)**:[21] ^{1}H NMR δ 0.74 (1H, ddd, H_a, J_{gem} = 4.6, J_{trans} = 5.8, J_{cis} = 8.5 Hz), 0.80–1.10 (5H, m), 1.23–1.49 (6H, m), 1.59 (1H, td, H_c, J_{gem}, J_{trans} = 5.8, J_{trans} = 8.5 Hz), 7.00–7.32 (5H, m).

***cis*-1-Butyl-2-phenylcyclopropane (*cis*-7a)**:[21] ^{1}H NMR δ 0.64 (1H, dt, H_a, J_{gem} = 5.0, J_{trans} = 6.1 Hz), 0.78 (3H, t, J = 6.4 Hz), 0.84–1.43 (8H, m), 2.11 (1H, dt, H_c, J_{trans} = 6.1, J_{cis} = 8.9 Hz), 7.01–7.35 (5H, m).

1-(*tert*-Butyl)-2-phenylcyclopropane (7b) (a 6.7:1 mixture of the cis and trans isomers): ^{1}H NMR δ 0.69 (9H, s, ^{t}Bu of the cis isomer), 0.90 (9H, s, ^{t}Bu of the trans isomer) 0.74–1.08 (3H, m), 1.75 (1H, td, H_c of the trans isomer, J_{trans} = 5.3, J_{cis} = 8.6 Hz), 2.14 (1H, dt, H_c of the cis isomer, J_{trans} = 6.7, J_{cis} = 8.4 Hz), 7.02–7.38 (5H, m); IR (liquid film) 1030 (s), 770 (s), 720 (s), 700 (s) cm^{-1}; MS m/z (relative intensity) 174 (M^+, 6), 131 (4), 117 (9), 104 (100), 91(9); HRMS calcd for $C_{13}H_{18}$ 174.1409, found 174.1413.

1-Ethyl-2-phenylcyclopropane (7c) (a 2.0:1 mixture of the cis and trans isomers): ^{1}H NMR δ 0.63 (1H, dt, H_a of the cis isomer, J_{gem} = 4.6, J_{trans} = 5.8 Hz), 0.68–1.28 (7H, m), 1.38 (1H, br q, H_c of the trans isomer, J = ca. 7 Hz), 2.11 (1H, dt, H_c of the cis isomer, J_{trans} = 6.0, J_{cis} = 8.3 Hz), 7.01–7.36 (5H, m); IR (liquid film) 1030, 770, 725, 700 cm^{-1}; MS m/z (relative intensity) 146 (M^+, 36) 117 (100), 104 (58), 91 (33); HRMS calcd for $C_{11}H_{14}$ 146.1096, found 146.1090.

***trans*-1-Butyl-2-[(phenylmethoxy)methyl]cyclopropane (*trans*-7d)**: ^{1}H NMR δ 0.24–0.40 (2H, H_a, H_b, m), 0.76–0.95 (4H, m), 1.00–1.46 (7H, m), 3.26 (1H, dd, J = 6.9, 10.2 Hz), 3.56 (1H, dd, J = 7.8, 14.3 Hz), 4.51 (2H, s), 7.21–7.42 (5H, m); IR (liquid film) 1100, 1075, 1030, 735, 700 cm^{-1}; MS m/z (relative intensity) 218 (M^+, 3), 188 (3), 91 (100); HRMS calcd for $C_{15}H_{22}O$ 218.1672, found 218.1672.

***cis*-1-Butyl-2-[(phenylmethoxy)methyl]cyclopropane (*cis*-7d)**: ^{1}H NMR δ −0.07 (1H, br q, H_a, J_{gem}, J_{trans} = ca. 5 Hz), 0.69 (1H, dt, H_b, J_{gem} = 4.5, J_{cis} = 8.5 Hz), 0.76–0.95 (4H, m), 1.00–1.50 (7H, m), 3.37 (1H, dd, J = 8.2, 10.2 Hz), 3.52 (1H, dd, J = 6.7, 10.2 Hz), 4.46 (1H, d, J = 12.4 Hz), 4.57 (1H, d, J = 12.4 Hz), 7.21–7.41 (5H, m); IR (liquid film) 1090, 1075, 1030, 730, 700 cm^{-1}; MS m/z (relative intensity) 218 (M^+, 2), 188 (2), 91 (100); HRMS calcd for $C_{15}H_{22}O$ 218.1672, found 218.1662.

1-*sec*-Butyl-2-[(phenylmethoxy)methyl]cyclopropane (7e) (a mixture of the stereoisomers): ^{1}H NMR δ −0.10 to +0.08 (1H, m), 0.54–1.68 (12H, m), 3.34–3.58 (2H, m), 4.42–4.62 (2H, m), 7.20–7.42 (5H, m); IR (liquid film) 1100, 1080, 740, 705 cm^{-1}.

***trans*-1-*tert*-Butyl-2-[(phenylmethoxy)methyl]cyclopropane (*trans*-7f)**: ^{1}H NMR δ 0.23 (1H, ddd, H_b, J_{gem} = 4.2, J_{trans} = 5.1, J_{cis} = 8.6 Hz), 0.40–0.60 (2H, H_a, H_d, m), 0.83 (9H, s), 0.96 (1H, H_c, m), 3.19 (1H, dd, J = 7.4, 10.2 Hz), 3.41 (1H, dd, J = 6.3, 10.2 Hz), 4.52 (2H, s), 7.19–7.42 (5H, m); IR (liquid film) 1105, 1080, 735, 700 cm^{-1}; MS m/z (relative intensity) 218 (M^+, 1), 188 (2), 177 (3), 161 (2), 91 (100); HRMS calcd for $C_{15}H_{22}O$ 218.1672, found 218.1671.

***cis*-1-*tert*-Butyl-2-[(phenylmethoxy)methyl]cyclopropane (*cis*-7f)**: ^{1}H NMR δ 0.23 (1H, dt, H_a, J_{gem} = 4.3, J_{trans} = 6.7 Hz), 0.66 (1H, dt, H_b, J_{gem} = 4.3, J_{cis} = 8.9 Hz), 0.77 (1H, dt, H_d, J_{trans} = 6.7, J_{cis} = 8.9 Hz), 0.93 (9H, s), 1.10 (1H, H_c, m), 3.58 (1H, dd, J = 7.7, 11.0 Hz), 3.63 (1H, dd, J = 7.7, 11.0 Hz), 4.48 (1H, d, J = 12.2 Hz), 4.56 (1H, d, J = 12.2 Hz), 7.22–7.42 (5H, m); IR (liquid film) 1100, 1090, 1085, 1030, 735, 700 cm^{-1}; MS m/z (relative intensity) 218 (M^+, 0.5), 188 (0.6), 91 (100).

***trans*-1-Methyl-2-[(phenylmethoxy)methyl]cyclopropane (*trans*-7g)**: ^{1}H NMR δ 0.26 (1H, td, H_b, J_{gem}, J_{trans} = 5.0, J_{cis} = 8.3 Hz), 0.34 (1H, td, H_a, J_{gem}, J_{trans} = 5.0, J_{cis} = 8.3 Hz), 0.60 (1H, m), 0.78 (1H, m), 1.04 (3H, d, J = 6.0 Hz), 3.30 (2H, d, J = 6.8 Hz), 4.52 (2H, s), 7.21–7.42 (5H, m); IR (liquid film) 1090, 1075, 1030, 735, 700 cm^{-1}; MS m/z (relative intensity) 176 (M^+, 2), 146 (6), 105 (6), 91 (100).

***cis*-1-Methyl-2-[(phenylmethoxy)methyl]cyclopropane (*cis*-7g)**: ^{1}H NMR δ −0.10 (1H, br q, H_a, J_{gem}, J_{trans} = ca. 5 Hz), 0.70 (1H, dt, H_b, J_{gem} = 4.6, J_{cis} = 8.2 Hz), 0.80–1.20 (5H, m, including d (3H, J = 5.0 Hz) at 1.06), 3.32 (1H, dd, J = 8.3, 10.2 Hz), 3.58 (1H, dd, J = 6.2, 10.2 Hz), 4.48 (1H, d, J = 11.9 Hz), 4.57 (1H, d, J = 11.9 Hz), 7.21–7.44 (5H, m); IR (liquid film) 1100, 1075, 1030, 735, 700 cm^{-1}; MS m/z (relative intensity) 176 (M^+, 3), 146 (7), 105 (5), 91 (100); HRMS calcd for $C_{12}H_{16}O$ 176.1202, found 176.1206.

1-Ethyl-2-[(phenylmethoxy)methyl]cyclopropane (7h) (a 8.0:1 mixture of the cis, trans isomer): ^{1}H NMR δ −0.06 (1H, br q, H_a of the cis isomer, J_{gem}, J_{trans} = ca. 5 Hz), 0.33 (1H, ddd, H_a of the trans isomer, J_{gem} = 3.5, J_{trans} = 4.6, J_{cis} = 8.9 Hz), 0.70 (1H, dt, H_b of the cis isomer, J_{gem} = 4.3, J_{cis} = 8.4 Hz), 0.74–1.54 (8H, m, including t (3H, J = 7.2 Hz) at 0.96), 3.22–3.60 (2H, m), 4.43–4.62 (2H, m), 7.19–7.44 (5H, m); IR (liquid film) 1095, 1075, 1030, 910, 735, 700 cm^{-1}; MS (relative intesnity) 190 (M^+, 1.6), 160 (3.2), 134 (3.6), 91 (100); HRMS calcd for $C_{13}H_{18}O$ 190.1358, found 190.1350.

***trans*-1-Butyl-2-hexylcyclopropane (*trans*-7i)**: ^{1}H NMR δ 0.12 (2H, t, H_a, H_b, J_{trans} = 6.2 Hz), 0.35 (2H, H_c, H_d, m), 0.81–0.96 (6H, m), 1.02–1.44 (10H, m); IR (liquid film) 2925, 1465, 1380, 1020 cm^{-1}; MS m/z (relative intensity) 182 (M^+, 3), 105 (10), 91 (100).

***cis*-1-Butyl-2-hexylcyclopropane (*cis*-7i)**: ^{1}H NMR δ −0.34 (1H, dt, H_a, J_{gem} = 3.4, J_{trans} = 5.0 Hz), 0.48–0.72 (3H, m), 0.81–0.97 (6H, m), 1.02–1.49 (16H, m); IR (liquid film) 2925, 1470, 1460, 1380, 1020 cm^{-1}; MS m/z (relative intensity) 182 (M^+, 10), 111 (12), 91 (54) (100); HRMS calcd for $C_{13}H_{26}$ 182.2036, found 182.2036.

***exo*-7-Butylnorcarane (*exo*-7j)**:[2] 1H NMR δ 0.30 (1H, tt, J = 4.7, 6.5 Hz), 0.47–0.57 (2H, m), 0.81–0.94 (3H, m), 1.04–1.40 (10H, m), 1.49–1.67 (2H, m), 1.72–1.92 (2H, m).

***endo*-7-Butylnorcarane (*exo*-7j)**:[2] ^{1}H NMR δ 0.54 (1H, tdd, J = 6.5, 8.1, 9.4 Hz), 0.74–0.98 (5H, m), 1.01–1.46 (12H, m), 1.70–1.92 (2H, m).

1-Butyl-2,2,3,3-tetramethylcyclopropane (7k): ^{1}H NMR δ 0.05 (1H, t, J = 6.6 Hz), 0.80–0.94 (9H, m), 1.02 (6H, s), 1.12–1.36 (6H, m); IR (liquid film) 2925, 1460, 1380, 940 cm^{-1}.

***r*-1-Bromo-1-chloro-*t*-2-phenylcyclopropane (11a)**.[19] To a solution of lithium carbenoid **8a** (R^1 = Ph) which was prepared from **5a** (15.2 mmol) as described in method B-1 at −85 °C was added CF_2ClCC_2F (2.2 mL, 18.2 mmol), and the mixture was stirred at this temperature for 0.5 h. The mixture was poured into aqueous HCl (1 N) and extracted twice with Et_2O. The combined organic layers were dried and concentrated in vacuo. Distillation of the residue (85–87 °C/3 mmHg) gave 1.29 g (37%) of **11a**.

***cis*-1-Chloro-2-phenylcyclopropane (12)**.[20] Bromochlorocyclopropane **11a** (148 mg, 0.64 mmol) was treated with 0.8 mmol of $(Bu)_3ZnLi$ at −85 °C for 24 h in a manner simialr to that described in the synthesis of bromocyclopropane **6a**. After workup flash chromatography (hexane) of the crude mixture gave 70.2 mg (72% yield) of **12**: ^{1}H NMR δ 1.26 (1H, ddd, H_a, J_{trans} = 4.3, J_{gem} = 6.8, J_{cis} = 7.6 Hz), 1.51 (1H, ddd, H_b, J_{gem} = 6.8, J_{cis} = 7.4, J_{trans} = 9.5 Hz), 2.38 (1H, td, H_c, J_{cis} = 7.6, J_{trans} = 9.5 Hz), 3.40 (1H, dt, H_d, J_{trans} = 4.3, J_{cis} = 7.3 Hz), 7.24–7.42 (5H, m).

***r*-1-Iodo-1-butyl-*t*-2-phenylcyclopropane (*trans*-14)[2] and *r*-1-Iodo-1-butyl-*c*-2-phenylcyclopropane (*cis*-14)[2]**. A solution of 1-butylcyclopropylzinc (4) in THF was prepared from dibromocycloproane **5a** (1.0 mmol) according to method A or B. To the resulting solution was added a solution of I_2 (2.2 mmol) in THF (5 mL) at 0 °C. After being stirred for 0.5 h at rt, the mixture was diluted with ether and washed successively with aqueous $NaHSO_3$ and aqueous $NaHCO_3$. The organic layer was dried and concentrated in vacuo. The residue was purified by flash chromatography (petroleum ether) to give *trans*- and *cis*-14 (method A; 94% yield, method B-1; 85% yield). ***trans*-14a**: R_f 0.6 (petroleum ether/benzene (90:10)); ^{1}H NMR δ 0.76 (3H, t, J = 7.2 Hz), 1.00–1.48 (7H, m, including t (1H, H_a, J_{gem}, J_{trans} = 6.8 Hz) at 1.26), 1.54 (1H, dd, H_b, J_{gem} = 6.8, J_{cis} = 9.7 Hz), 2.85 (1H, dd, H_c, J_{trans} = 7.0, J_{cis} = 9.7 Hz), 7.17–7.38 (5H, m). ***cis*-14a**: R_f 0.5 (petroleum ether/benzene (90:10); ^{1}H NMR δ 0.95 (3H, t, J = 7.2 Hz), 1.23–1.71 (8H, m), 1.91 (1H, m), 7.13–7.40 (5H, m).

General Procedure for Palladium(0)-Catalyzed Coupled of 1-Alkylcyclopropylzinc Intermediate 4. A THF solution of 1-alkylcyclopropylzinc 4 was prepared from dibromocyclopropane **5** (1.0 mmol) according to method A, B, or C. To this solution at 0 °C was added a THF suspension of $Pd(PPh_3)_2$ which was prepared by the reaction of $PdCl_2(PPh_3)_2$ (0.10 mmol) with DIBALH (0.2 mmol, 1 M in toluene) in THF (2 mL) at 0 °C for 15 min. After addition of a proper electrophile (3.0 mmol), the reaction mixture was stirred at rt for 12–24 h. The mixture was poured into aqueous HCl (1 N) and extracted twice with ether. The combined organic layers were washed with aqueous $NaHCO_3$, dried, and then concentrated in vacuo. Purification by Kugelrohr distillation and/or silica gel flash chromatography gave **15a–*j*** and **16a–f**.

***r*-1-Acetyl-1-butyl-*t*-2-phenylcyclopropane (*trans*-15a)**.[2] Isolated by flash chromatography (petroleum ether/EtOAc (98:2)) of the residue after Kugelrohr distillation (120 °C/3 mmHg): R_f 0.4 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.75 (3H, t, J = 6.8 Hz), 0.80–1.35 (6H, m), 1.66 (1H, m), 1.75 (1H, ddd, H_b, J_{ae} = 1.3, J_{gem} = 4.9, J_{cis} = 9.0 Hz), 2.21 (3H, s), 2.64 (1H, dd, H_c, J_{trans} = 7.1, J_{cis} = 9.0 Hz), 7.10–7.38 (5H, m).

***r*-1-Acetyl-1-butyl-*c*-2-phenylcyclopropane (*cis*-15a)**.[2] Isolated by a procedure similar to that for the trans isomer: R_f 0.5 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.84–0.97 (3H, m), 1.06 (1H, dd, H_b, J_{gem} = 5.4, J_{cis} = 8.6 Hz), 1.10–1.46 (5H, m), 1.76 (3H, s), 1.98 (1H, ddd, H_a, $J_{a,e}$ = 1.4, J_{gem} = 5.4, J_{trans} = 6.7 Hz), 2.35 (1H, m, H_c), 2.40 (1H, m, He), 7.06–7.33 (5H, m).

***r*-1-Benzoyl-1-butyl-*t*-2-phenylcyclopropane (*trans*-15b)**. Isolated by flash chromatography (petroleum ether/EtOAc, gradient elution from 98:2 to 95:5) of the residue after Kugelrohr distillation (136 °C/0.7 mmHg): ^{1}H NMR δ 0.61 (3H, t, J = 7.2 Hz), 0.78–1.38 (6H, m), 1.70 (1H, m), 1.92 (1H, ddd, H_b, J_{be} = 1.1, J_{gem} = 5.0, J_{cis} = 9.2 Hz), 2.46 (1H, dd, H_c, J_{trans} = 6.9, J_{cis} = 9.2 Hz), 7.19–7.55 (8H, m), 7.80–7.90 (2H, m); IR (liquid film) 1675, 1605, 1220, 1180, 795, 780, 750, 700 cm^{-1}.

***r*-1-Benzoyl-1-butyl-*c*-2-phenylcyclopropane (*cis*-15b)**.[9a] Isolated by a procedure similar to that for the trans isomer: ^{1}H NMR δ 0.75 (3H, t, J = 7.2 Hz), 0.88–1.43 (6H, m), 2.08 (1H, ddd, H_a, J_{ae} = 1.5, J_{gem} = 5.5, J_{trans} = 6.6 Hz), 2.48 (1H, dd, H_c, J_{trans} = 6.6, J_{cis} = 8.5 Hz), 2.52 (1H, m, H_e), 7.20–7.55 (8H, m), 7.57–7.73 (2H, m).

***r*-1-(Ethoxycarbonyl)-1-butyl-*t*-2-phenylcyclopropane (*trans*-15c)**. Isolated by flash chromatography (petroleum ether/EtOAc, gradient elution from 98:2 to 95:5): R_f 0.55 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.73 (3H, t, J = 6.8 Hz), 1.00–1.36 (6H, m, including dd (1H, H_a, J_{gem} = 4.6, J_{trans} = 7.3 Hz) at 1.36), 1.27 (3H, t, J = 7.2 Hz), 1.56 (1H, m), 1.65 (1H, ddd, H_b, J_{be} = 1.0, J_{gem} = 4.6, J_{cis} = 9.1 Hz), 2.74 (1H, dd, Hc, J_{trans} = 7.3, J_{cis} = 9.1 Hz), 4.17 (2H, qd, J = 7.2, 10.6 Hz), 7.10–7.35 (5H, m); IR (liquid film) 1720, 1200, 1155, 870, 765, 720, 700 cm^{-1}; MS m/z (relative intensity) 246 (M^+, 67), 203 (28), 173 (45), 157 (39), 129 (71), 117 (100), 104 (47), 91 (91); HRMS calcd for $C_{16}H_{22}O$ 246.1621, found 246.1617.

***r*-1-(Ethoxycarbonyl)-1-butyl-*c*-2-phenylcyclopropane (*cis*-15c)**. Isolated by a procedure similar to that for the trans isomer: R_f 0.55 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.80 (3H, t, J = 7.1 Hz), 0.91 (3H, t, J = 6.8 Hz), 1.08 (1H, dd, H_b, J_{gem} = 5.0, J_{cis} = 8.6 Hz), 1.13–1.54 (5H, m), 1.91 (1H, ddd, H_a, J_{ae} = 1.3, J_{gem}, 5.0, J_{trans} = 7.1 Hz), 2.20 (1H, m, H_e), 2.31 (1H, dd, H_c, J_{trans} = 7.5, J_{cis} = 8.6 Hz), 3.73 (2H, ABX_3, J_{AX}, J_{BX} = 7.0, J_{AB} = 10.8 Hz), 7.10–7.35 (5H, m); IR (liquid film) 1720, 1200, 1150, 785, 760, 725, 700 cm^{-1}; MS m/z (relative intensity) 246 (M^+, 75), 203 (32), 173 (45), 157 (40), 129 (72), 117 (100), 104 (46), 91 (91); HRMS calcd for $C_{16}H_{22}O$ 246.1621, found 246.1618.

***r*-1-Acetyl-1-ethyl-*t*-2-phenylcyclopropane (*trans*-15d)**. Isolated by flash chromatography (petroleum ether/EtOAc (98:2)) of the residue after Kugelrohr distillation (115 °C/30 mmHg): R_f 0.3 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.84 (3H, t, J = 7.0 Hz), 0.92 (1H, qd, J = 7.8, 16.2 Hz), 1.19 (1H, dd, H, J_{gem} = 4.8, J_{trans} = 7.3 Hz), 1.65–1.85 (2H, m, including ddd (1H, H, J_{be} = 1.2, J_{gem} = 4.8, J_{cis} = 9.0) at 1.72), 2.22 (3H, s), 2.70 (1H, dd, H_c, J_{trans} = 7.3, J_{cis} = 9.0), 7.10–7.37 (5H, m); IR (liquid film) 1685, 1240, 1205, 1140, 780, 735, 700 cm^{-1}; MS m/z (relative intensity) 188 (M^+, 100), 145 (100), 117 (37), 91 (59); HRMS calcd for $C_{13}H_{16}O$ 188.1202, found 188.1201.

***r*-1-Acetyl-1-ethyl-*c*-2-phenylcyclopropane (*cis*-15d)**. Isolated by a procedure similar to that for the trans isomer: R_f 0.35 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 1.01 (3H, t, J = 7.0 Hz), 1.06 (1H, dd, H_b, J_{gem} = 5.5, J_{cis} = 8.6 Hz), 1.35 (qd, J = 6.6, 14.6 Hz), 1.37 (3H, s), 1.96 (1H, ddd, Ha, J_{ae} = 1.3, J_{gem} = 5.5, J_{trans} = 6.8 Hz), 2.28–2.49 (2H, m, H_c, H_e), 7.08–7.34 (5H, m); IR (liquid film) 1700, 1140, 770, 735, 700 cm^{-1}; MS m/z (relative intensity) 188 (M^+, 100), 145 (89), 117 (36), 91 (51); HRMS calcd for $C_{13}H_{16}O$ 188.1202, found 188.1195.

1-Acetyl-1-*sec*-butyl-2-phenylcyclopropane (15e) (a mixture of stereoisomers). Isolated by flash chromatography (petroleum ether/EtOAc (98:2)): ^{1}H NMR δ 0.65–2.0 (11H, m), 2.40, 2.43 (3H, s), 2.80 (1H, m), 7.17–7.35 (5H, m).

***r*-1-Acetyl-1-*tert*-butyl-*t*-2-phenylcyclopropane (*trans*-15f)**. Isolated by flash chromatography (hexane/EtOAc (98:2)); R_f 0.45 (hexane/EtOAc (80:20)); ^{1}H NMR δ 0.83 (9H, s), 1.42 (1H, dd, H_b, J_{gem} = 5.9, J_{cis} = 9.7 Hz), 1.55 (1H, dd, H_a, J_{gem} = 5.9, J_{trans} = 7.2 Hz), 2.25 (3H, s), 2.35 (1H, dd, H_c J_{trans} = 7.2, J_{cis} = 9.7 Hz), 7.20–7.35 (5H, m).

***r*-1-Acetyl-1-butyl-*t*-2-[(phenylmethoxy)methyl]cyclopropane (*trans*-15g)**. Isolated by flash chromatography (petroleum ether/EtOAc, gradient elution from 97:3 to 90:10) of the residue after Kugelrohr distillation (125 °C/3 mmHg): R_f 0.3 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.55 (1H, dd, H_a, J_{gem} = 4.6, J_{cis} = 6.6 Hz), 0.82–0.94 (3H, m), 1.20–1.50 (5H, m), 1.64–1.92 (2H, m), 2.08 (3H, s), 3.41 (1H, dd, J = 8.2, 10.7 Hz), 3.62 (1H, dd, J = 5.8, 10.7 Hz), 4.47 (1H, d, J = 12.1 Hz), 4.55 (1H, d, J = 12.1 Hz), 7.23–7.41 (5H, m); IR (liquid film) 1690, 1145, 1095, 740, 700 cm^{-1}; MS m/z (relative intensity) 260 (M^+, 0.8), 169 (6), 154 (10), 91 (100); HRMS calcd for $C_{17}H_{24}O_2$ 260.1777, found 260.1764.

***r*-1-Acetyl-1-butyl-*c*-2-[(phenylmethoxy)methyl]cyclopropane (*cis*-15g)**. Isolated by a procedure similar to that for

(19) Fedorynski, M. *Synthesis* **1977**, 783.
(20) Hauser, J. W.; Pinkowski, N. J. *J. Am. Chem. Soc.* **1967**, *89*, 6981.

the trans isomer: R_f 0.1 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.66 (1H, dd, H_b, J_{gem} = 4.2, J_{cis} = 8.2 Hz), 0.81–0.94 (3H, m), 1.02 (1H, m), 1.18–1.50 (6H, m), 2.28 (3H, s), 2.38 (1H, m,), 3.01 (1H, dd, J = 9.4, 10.3 Hz), 3.63 (1H, dd, J = 4.8, 10.3 Hz), 4.36 (2H, s), 7.20–7.40 (5H, m); IR (liquid film) 1695, 1145, 1090, 735, 700 cm^{-1}; MS m/z (relative intensity) 260 (M^+, 0.1), 217 (0.9), 154 (6.1), 91 (100).

***r*-1-Acetyl-1-butyl-*t*-2-hexylcyclopropane (*trans*-15h).** Isolated by flash chromatography (petroleum ether/Et_2O (98:2)): R_f 0.15 (petroleum ether/Et_2O (95:5)); ^{1}H NMR δ 0.38 (1H, dd, H_a, J_{gem} = 4.2, J_{trans} = 5.8 Hz), 0.80–0.95 (6H, m), 1.14–1.54 (17H, m), 1.88 (1H, m), 2.04 (3H, s); IR (liquid film) 1690, 1145, 735 cm^{-1}; MS m/z (relative intensity) 224 (M^+, 27), 181 (100), 153 (13), 123 (15), 111 (22), 95 (25), 85 (38); HRMS calcd for $C_{15}H_{28}O$ 224.2141, found 224.2138.

***r*-1-Acetyl-1-butyl-*c*-2-hexylcyclopropane (*cis*-15h).** Isolated by a procedure similar to that for the trans isomer: R_f 0.25 (petroleum ether/Et_2O (95:5)); ^{1}H NMR δ 0.61 (1H, dd, H_b, J_{gem} = 4.2, J_{cis} = 8.1 Hz), 0.76–1.44 (23H, m), 2.13–2.36 (4H, m, including s (3H) at 2.21); IR (liquid film) 1695, 1150, 735 cm^{-1}; MS m/z (relative intensity) 224 (M^+, 22), 181 (100), 167 (13), 153 (13), 123 (24), 111 (32), 95 (38), 85 (78); HRMS calcd for $C_{15}H_{28}O$ 224.2141, found 224.2154.

1-Benzoyl-1-butyl-2-hexylcyclopropane (15i) (a 1.4:1 mixture of the trans and cis isomer). Isolated by flash chromatography (petroleum ether/Et_2O (98:2)) of the residue after Kugelrohr distillation 120 °C/1 mmHg: R_f 0.15 (petroleum ether/Et_2O (95:5)); ^{1}H NMR δ 0.37 (1H, dd, J = 4.3, 5.9 Hz), 0.60 (20H, m), 1.74 (1H, m), 2.04 (2H, m), 2.33 (1H, m), 7.20–7.62 (3H, m), 7.74–7.94 (3H, m); IR (liquid film) 1670, 1175, 910, 730, 710 cm^{-1}; MS m/z (relative intensity) 286 (M^+, 13), 243 (40), 105 (100), 91 (13); HRMS calcd for $C_{20}H_{30}O$; 286.2298, found; 286.2294.

1-Acetyl-1-butyl-2,2,3,3-tetramethylcyclopropane (15j). Isolated by flash chromatography (petroleum ether/EtOAc (98:2)); R_f 0.4 (petroleum ether/EtOAc (90:10)); ^{1}H NMR δ 0.85 (3H, t, J = 6.8 Hz), 1.01 (6H, s), 1.05 (6H, s), 1.08–1.35 (4H, m), 1.52–1.67 (2H, m), 2.05 (3H, s); IR (liquid film) 1700, 1175, 1105, 940 cm^{-1}; MS m/z 196 (M^+, 9), 181 (100), 153 (77), 84 (43); HRMS calcd for $C_{13}H_{24}O$ 196.1828, found 196.1818.

***r*-1-Butyl-1,*c*-2-diphenylcyclopropane (*trans*-16a).** Isolated by flash chromatography (hexane) of the residue after Kugelrohr distillation 150 °C/10 mmHg: R_f 0.55 (hexane/benzene (90:10)); ^{1}H NMR δ 0.60–0.72 (3H, m), 0.92–1.53 (8H, m, including dd (1H, H_a, J_{gem} = 5.0, J_{trans} = 6.2 Hz) at 1.18 and ddd (1H, H_b, J_{be} = 1.2, J_{gem} = 5.0, J_{cis} = 8.7 Hz) at 1.40), 2.34 (1H, dd, H_c, J_{trans} = 6.2, J_{cis} = 8.7 Hz), 7.14–7.46 (10H, m); IR (liquid film) 1600, 765, 730, 700 cm^{-1}; MS m/z (relative intensity) 250 (M^+, 21), 193 (100), 115 (61); HRMS calcd for $C_{19}H_{22}$ 250.1723, found 250.1714.

***r*-1-Butyl-1,*t*-2-diphenylcyclopropane (*cis*-16a).** Isolated by a procedure similar to that for the trans isomer: R_f 0.55 (hexane/benzene (90:10)); ^{1}H NMR δ 0.76–0.90 (3H, m), 0.96–1.52 (7H, m), 1.91 (1H, m), 2.19 (1H, dd, H_c, J_{trans} = 5.8, J_{cis} = 8.6 Hz), 6.67–6.84 (2H, m), 6.96–7.23 (8H, m); IR (liquid film) 1600, 775, 745, 700 cm^{-1}; MS m/z (relative intensity) 250 (M^+, 22), 193 (100), 115 (89); HRMS calcd for $C_{19}H_{22}$ 250.1723, found 250.1711.

***r*-1-Butyl-1-(2-propenyl)-*c*-2-phenylcyclopropane (*trans*-16b).** Isolated by flash chromatography (hexane): R_f 0.7 (hexane/benzene (90:10)); ^{1}H NMR δ 0.73 (2H, m), 0.82–1.40 (8H, m), 1.83 (3H, br s), 2.01 (1H, dd, H_c, J_{trans} = 6.3, J_{cis} = 8.6 Hz), 4.80 (2H, brs), 7.02–7.35 (5H, m); IR (liquid film) 1645, 1605, 895, 780, 700 cm^{-1}: MS m/z (relative intensity) 214 (M^+, 23), 157 (100), 129 (50), 91 (50); HRMS calcd for $C_{16}H_{22}$ 214.1732, found 214.1712.

***r*-1-Butyl-1-(2-propenyl)-*t*-2-phenylcyclopropane (*cis*-16b).** Isolated by a procedure similar to that for the trans isomer: R_f 0.7 (hexane/benzene (90:10)); ^{1}H NMR δ 0.80–0.99 (5H, m), 1.33–1.40 (8H, m, including br s (3H) at 1.29), 1.94 (1H, dd, H_c, J_{trans} = 5.8, J_{cis} = 8.3 Hz), 2.60 (1H, m), 4.82 (2H, m), 7.02–7.35 (5H, m); IR (liquid film) 1645, 1605, 1500, 775, 730, 700 cm^{-1}; MS m/z (relative intensity) 214 (M^+, 24), 157 (100), 129 (52), 91 (45); HRMS calcd for $C_{16}H_{22}$ 214.1723, found 214.1720.

***r*-1-Butyl-1-(2-methyl-1-propenyl)-*c*-2-phenylcyclopropane (*trans*-16c).** Isolated by Kugelrohr distillation 90–100 °C/2 mmHg: R_f 0.5 (hexane); ^{1}H NMR δ 0.70 (3H, t, J = 7.0 Hz), 0.80–1.44 (8H, m), 1.69 (3H, br s), 1.79 (3H, br s), 2.06 (1H, ,dd, Hc, J_{trans} = 6.1, J_{cis} = 8.3 Hz), 5.40 (1H, br s), 7.09–7.35 (5H, m); IR (liquid film) 1650, 1500, 830, 700 cm^{-1}; MS m/z (relative intensity) 228 (M^+, 5), 213 (50), 171 (100), 143 (25), 129 (29), 91 (58); HRMS calcd for $C_{17}H_{24}$ 228.1879, found 228.1882.

***r*-1-Butyl-1-(2-methyl-1-propenyl)-*t*-2-phenylcyclopropane (*cis*-16c).** Isolated by a procedure similar to that for the trans isomer: R_f 0.5 (hexane); ^{1}H NMR δ 0.88 (3H, t, J = 7.1 Hz), 0.98 (1H, br t, H_a, J_{gem}, J_{trans} = ca. 5.Hz), 1.10 (1H, dd, H_b, J_{gem} = 4.7, J_{cis} = 8.6 Hz), 1.14–1.46 (6H, m), 1.55 (3H, br s), 1.61 (1H, br s), 1.84 (1H, dd, H_c, J_{trans} = 6.1, J_{cis} = 8.6 Hz), 4.86 (1H, br s), 6.95–7.05 (2H, m), 7.06–7.30 (3H, m); IR (liquid film) 1605, 1500, 835, 695 cm^{-1}; MS m/z (relative intensity) 228 (M^+, 4), 213 (49), 171 (100), 143 (27), 129 (32), 91 (59); HRMS calcd for $C_{17}H_{24}$ 228.1879, found 228.1879.

***r*-1-Butyl-1-phenyl-*c*-2-[(phenylmethoxy)methyl]cyclopropane (*trans*-16d).** Isolated by flash chromatography (hexane/Et_2O (98:2)): R_f 0.3 (hexane/Et_2O (95:5)); ^{1}H NMR δ 0.51 (1H, dd, H_a, J_{gem} = 4.8, J_{cis} = 5.8 Hz), 0.74–0.86 (3H, m), 1.08 (1H, ddd, H_b, J_{be} = 0.7, J_{gem} = 4.5, J_{trans} = 9.1 Hz), 1.12–1.55 (7H, m), 1.67 (1H, m), 3.58 (1H, dd, J = 8.1, 10.6 Hz), 3.70 (1H, dd, J = 6.4, 10.6 Hz), 4.55 (1H, d, J = 12.1 Hz), 4.64 (1H, d, J = 12.1 Hz), 7.11–7.46 (10H, m); IR (liquid film) 1605, 1090, 1080, 1030, 765, 740, 700 cm^{-1}; MS m/z (relative intensity) 294 (M^+, 0.05), 203 (11), 129 (24), 117 (28), 91 (100).

***r*-1-Butyl-1-phenyl-*t*-2-[(phenylmethoxy)methyl]cyclopropane (*cis*-16d).** Isolated by a procedure similar to that for the trans isomer: R_f 0.3 (hexane/Et_2O (95:5)); ^{1}H NMR δ 0.72–0.88 (5H, m), 1.06–1.37 (6H, m), 1.87 (1H, m), 3.01 (1H, dd, J = 7.5, 9.9 Hz), 3.09 (1H, dd, J = 6.6, 9.9 Hz), 4.25 (1H, d, J = 11.8 Hz), 4.34 (1H, d, J = 11.8 Hz), 7.08–7.43 (10H, m); IR (liquid film) 1600, 1075, 1030, 765, 700 cm^{-1}; MS m/z (relative intensity) 294 (M^+, 0.2), 203 (11), 129 (26), 117 (30), 91 (100).

1-Butyl-1-(propen-2-yl)-*c*-2-[(phenylmethoxy)methyl]cyclopropane (16e) (a 2.0:1 mixture of the trans and cis isomers). Isolated by flash chromatography (hexane/Et_2O (98:2)): R_f 0.3 (hexane/Et_2O (95:5)); ^{1}H NMR δ 0.25 (1H, dd, H_a of the trans isomer, J_{gem} = 4.5, J_{trans} = 5.8 Hz), 0.78–0.95 (4H, m), 1.01–1.35 (7H, m), 1.64 (3H, brs, CH_3 of the cis isomer), 1.74 (3H, br s, CH_3 of the trans isomer), 3.30–3.47 (2H, m), 4.66–4.76 (2H, m), 7.20–7.42 (5H, m); IR (liquid film) 1645, 1495, 895, 735, 700 cm^{-1}; MS m/z (relative intensity) 258 (M^+, 1), 167 (5), 149 (4), 107 (13), 91 (100); HRMS calcd for $C_{18}H_{26}O$ 258.1985, found 258.1991.

1-Butyl-2,2,3,3-tetramethyl-1-(4-acetylphenyl)cyclopropane (16f). Isolated by flash chromatography (hexane/EtOAc (99:1)): R_f 0.5 (hexane/EtOAc (80:20)); ^{1}H NMR δ 0.76 (3H, t, J = 6.8 Hz), 0.87 (6H, s), 0.99–1.30 (10H, m, including s (6H) at 1.17), 1.55 (2H, m), 2.57 (3H, s), 7.06–7.32 (2H, m), 7.80–7.93 (2H, m); IR (liquid film) 1680, 1605, 950, 845, 830 cm^{-1}; MS m/z (relative intensity) 272 (M^+, 78), 257 (83), 215 (100), 173 (46); HRMS calcd for $C_{19}H_{28}O$ 272.2141, found 272.2138.

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Supplementary Material Available: ^{1}H NMR spectra of **7b–i,k, 15b–j,** and **16a–f** (37 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.