Copper(I)-Promoted Dechlorinative Surzur–Tanner Rearrangement of 2,2,2-Trichloroethyl Carboxylates
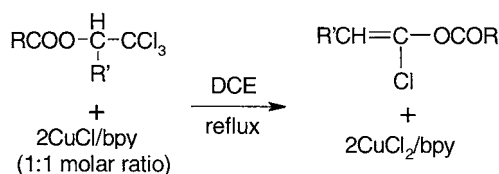
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ABSTRACT

2,2,2-Trichloroethyl carboxylates undergo highly efficient dechlorinative Surzur–Tanner rearrangement with 2 equiv of a 1:1 molar mixture of CuCl and bpy in boiling DCE to give 1-chloroethenyl carboxylates in which copper appears to play an important role, probably by coordinating the initial radical or as a Lewis acid catalyst.

The intramolecular 1,2-suprafacial migration of the acyloxy group in β-acyloxyalkyl radicals, known as the Surzur–Tanner rearrangement, has fascinated experimental as well as theoretical chemists because of its mechanistic intrigue and synthetic potential.[1] The most popular way of generating the initial β-acyloxyalkyl radical is by the reaction of a β-acyloxyalkyl halide with Bu$_3$SnH/AIBN (Scheme 1). The

Scheme 1. Surzur–Tanner Rearrangement of β-Acyloxyalkyl Halides
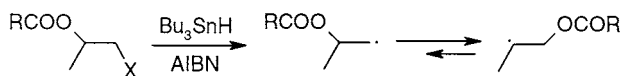
rearranged radical abstracts a hydrogen atom from Bu$_3$SnH to complete the rearrangement. The reaction proceeds in the direction of the more stable β-acyloxyalkyl radical and does not occur in the absence of a significant driving force. It has been exploited for a very convenient and practical synthesis of 2-deoxypyranoses, for which an *Organic Synthesis* protocol has been presented.[2] It is also useful for stereoselective preparation of α-ribonucleosides,[3] ring contraction–ring expansion of lactones,[4] and some steroidal transformations.[5] However, this is a reductive rearrangement and the valuable halogen functionality used for initiating the reaction is lost, thus limiting the scope for further transformations. Moreover, the rearrangement is rather slow in many cases as compared to typical radical reactions such as hydrogen abstraction. Therefore, direct reduction of the β-acyloxyalkyl halide competes with or even predominates over the reductive rearrangement even under dilute conditions. Recently, in accordance with theoretical prediction,[6] a dramatic increase in the rate of this rearrangement has been reported for Lewis acid-catalyzed rearrangement of a few β-acyloxyalkyl halides capable of chelating the catalyst through the ester carbonyl oxygen and a proximal hydroxy

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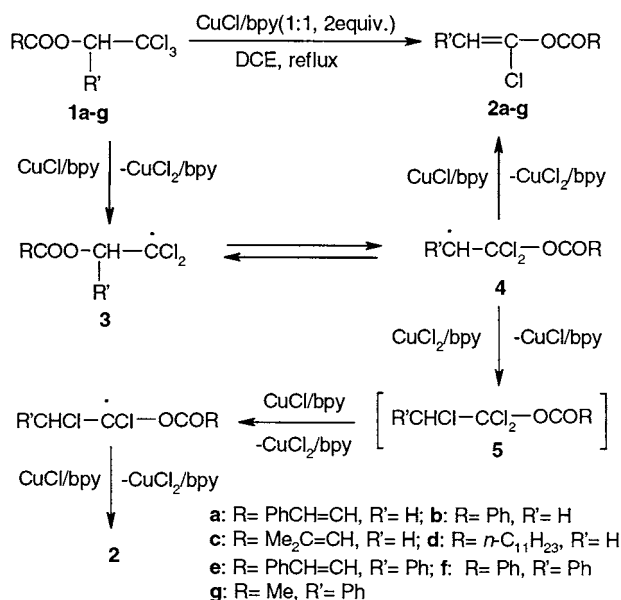
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Scheme 2. Dechlorinative Surzur−Tanner Rearrangement of 2,2,2-Trichloroethyl Carboxylates

a: R= PhCH=CH, R'= H; b: R= Ph, R'= H
c: R= Me₂C=CH, R'= H; d: R= n-C₁₁H₂₃, R'= H
e: R= PhCH=CH, R'= Ph; f: R= Ph, R'= Ph
g: R= Me, R'= Ph

Table 1. CuCl/bpy-Promoted Dechlorinative Rearrangement of 2,2,2-Trichloroethyl Carboxylates (**1**) to 1-Acyloxy-1-chloroethenes (**2**)

entry	ester[a] **1**	solvent	time (h)	product **2**	yield (%)
1	**1a**	DCE	3	**2a**	92
		benzene	3	**1a, 2a**	39, 45[b]
		THF	6	**1a:2a**	10:90[c]
2	**1b**	DCE	2	**2b**	93
3	**1c**	DCE	3	**2c**	90
4	**1d**	DCE	2	**2d**	98
5	**1e**	DCE	4	**2e**	84
6	**1f**	DCE	2.5	**2f**	97
7	**1g**	DCE	2.5	**2g**	91

[a] Concentration = 0.125 M. [b] Yields calculated from ^{1}H NMR spectra of the mixture. [c] Molar ratio, calculated from ^{1}H NMR spectra of the mixture.

group.[7] However, small proportions of the products of direct reduction still persisted.

Transition metal complexes are known to abstract a halogen atom homolytically from polyhalo and other active halogen compounds to produce radicals by a redox reaction. The metal halide in the higher oxidation state thus formed is a good halogen transfer agent and controls the reactivity of the radical by transferring the halogen atom strategically during the subsequent radical reactions. These radicals have been exploited in what are known as halogen atom transfer radical (HATR) addition/cyclization[8−10] and living polymerization[11] reactions, which are at the focus of great current interest. Our experience in HATR cyclization[12] led us to use, for the first time, a suitable transition metal complex to generate the initial radical in the Surzur−Tanner rearrangement under nonreducing conditions. This strategy was expected not only to obviate the problem of direct reduction and loss of halogen functionality but also to allow the reaction to be carried out at higher concentrations. Lewis acid catalysis[6] by the metal complex was also envisioned.

Thus, 2,2,2-trichloroethyl carboxylates **1** (Scheme 2) were treated with a mixture of CuCl and bpy (1:1 molar ratio) in DCE (1,2-dichloroethane) at reflux under a nitrogen atmo-

sphere to realize the above expectations. The reaction proceeded smoothly to give 1-chloroalkenyl carboxylates **2** in high yields without any significant side products (Table 1), apparently by migration of the acyloxy group followed by elimination of a chlorine atom, and required 2 equiv of the CuCl/bpy reagent for completion. The structures of the products were established by their spectral analysis and hydrolysis. Though the expected formation of **5** by transfer of a chlorine atom to the rearranged radical **4** from CuCl₂/bpy was not observed, it was not disappointing in view of the fact that a new carbon−carbon double bond functionality was created in the product, providing greater latitude for further manipulation. The observed elimination of a chlorine atom after the rearrangement suggested that the elimination in the rearranged radical is faster than chlorine atom abstraction from CuCl₂/bpy probably due, among other factors, to the relief in steric strain. It is possible that **5** is a true stable intermediate that is converted into **2** by a subsequent radical reaction. The reaction proceeds faster than many reported β-acyloxyalkyl radical rearrangements as revealed by a much shorter reaction time (2−4 h, Table 1) that compares well with that reported for some of the synthetically useful faster category of reactions (∼6 h).[2−5] Interestingly, an apparently more stable radical (**3**, R′ = H) rearranges to a less stable radical (**4**, R′ = H). Probably, the availability of an inherent mechanism for stabilization of the rearranged radical **4** by elimination of a chlorine atom or the lower reactivity of the transferred chlorine atom in intermediate **5** toward further abstraction drives the equilibrium in the forward direction and forces it to occur in a direction opposite to what has generally been observed so far. Phenyl migration, which has been reported to compete with this rearrangement,[13] was not observed in the case of substrates **1e**−**g**. Crossover experiments on a mixture of **1d** and **1e** gave only **2d** and **2e** without any detectable crossover products. The reaction of **1a** was not inhibited by 4-tert-butylcatechol in accordance with other Cu(I)-catalyzed

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Table 2. Reaction of 2,2,2-Trichloroethyl Esters **1d** and **1a** in the Presence of Bu$_3$SnH in Boiling Benzene

entry	ester	Bu$_3$SnH (equiv)	time (h)	product[a]	yield (%)
1	**1d**	2.5[b]	4	**6**	95
2	**1d**	1.5[c]	6	**7**	81
3	**1a**	1.5[c]	6	**8**	74
4	**1a**	1.5[d] (+2 equiv of CuCl/bpy)	5	**1a:2a:8**	3:79:18[e]

[a] Product **6** = n-C$_{11}$H$_{23}$CO$_2$CH$_2$CH$_2$Cl, **7** = n-C$_{11}$H$_{23}$CO$_2$CH$_2$CHCl$_2$, and **8** = PhCH=CHCO$_2$CH$_2$CHCl$_2$. [b] Bu$_3$SnH (0.25 M solution) in benzene containing 0.01 equiv of AIBN was added to a 0.1 M solution of **1d** in benzene over 1.5 h. [c] Bu$_3$SnH (0.075 M solution) in benzene containing 0.01 equiv of AIBN was added to a 0.04 M solution of **1a** (or **1d**) in benzene over 4 h. [d] A mixture containing 0.15 M Bu$_3$SnH, 0.1 M **1a**, and 2 equiv of Cu(I)/bpy in benzene without AIBN was used. [e] Molar ratio, calculated from ^{1}H NMR spectra of the mixture.

HATR reactions.[14] The reaction of **1b** with dibenzoyl peroxide or AIBN did not give the rearranged product **2b**. 2,2-Dichloroethyl benzoate was found to be inert under our experimental conditions.

For comparison, the rearrangement was attempted under the conventional conditions using Bu$_3$SnH/AIBN. However, only reductive dechlorination was observed without any indication of rearrangement even under reaction conditions that are known to favor the rearrangement (dilute solution, slow addition of Bu$_3$SnH, Table 2, entries 2 and 3). In contrast, the CuCl/bpy-promoted reaction of **1a** in the presence of a considerably higher concentration of Bu$_3$SnH, which is expected to favor direct reduction and reductive trapping of the radical intermediates, gave predominantly the rearranged product **2a** (Table 2, entry 4), indicating that the radical intermediates in the CuCl/bpy-promoted reaction and Bu$_3$SnH/AIBN-promoted reaction have different reactivities and selectivities, and thus are not exactly the same.

The nature of the radical species involved in metal-catalyzed HATR reactions has been a subject of considerable debate.[15] For copper-catalyzed HATR reactions, either free[14,16] or copper-coordinated[10a,17] radicals have been proposed to be involved. In the present study, the higher relative
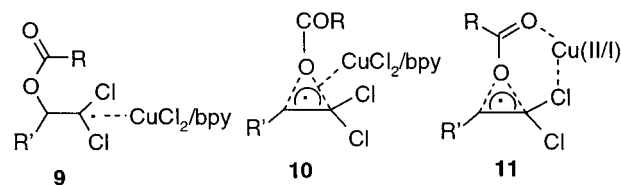

Figure 1.

reactivity of the initial radical generated by the reaction of **1** with CuCl/bpy toward rearrangement compared to hydrogen abstraction from Bu$_3$SnH may be due to initial formation of a copper-coordinated radical **9** (Figure 1) or Lewis acid catalysis by the copper(I)[18] or copper(II) complex involving transition structures **10** and **11**, respectively. The higher reactivity of the copper-complexed radical **9** toward rearrangement might be due to the enhanced electrophilicity of the copper-complexed radical facilitating an S$_{NR}$2′ mechanism[19] or due to stabilization of the three-center three-electron transition structure **10** as a result of withdrawal of the unpaired electron from the three-membered ring, making it assume aromatic-like character.[20] The lower reactivity toward hydrogen abstraction is understandable on the basis of the lower odd electron density at the carbon atom in the copper-complexed radical **9**. It is possible that Lewis acid catalysis works on the copper-complexed radical also.

In conclusion, a transition metal complex has been used for the first time to generate β-acyloxyalkyl radicals in Surzur−Tanner rearrangement under nonreducing conditions. The present Cu(I)-promoted reaction has some interesting features and adds a new dimension to this fascinating reaction in which copper appears to play an important role.

Supporting Information Available: Experimental details and spectral data of all the compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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