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Effective cleavage of ditertiary glycols via vanadium(V)-catalyzed aerobic oxidation

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ABSTRACT

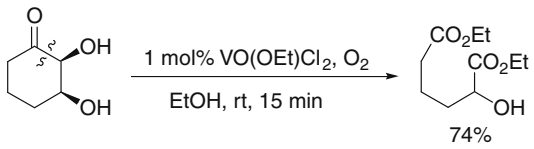
The aerobic oxidation of ditertiary glycols catalyzed by oxytrichlorovanadium resulted in carbon–carbon bonds cleavage producing the ketones efficiently.

The oxidative cleavage of carbon–carbon bonds in 1,2-diols (glycols) is a very important reaction which has frequently been utilized in organic syntheses.[1] Despite the importance of the oxidative cleavage of glycols, there are not very many reagents that can be used for these reactions.[2] Representative oxidants include periodates[3] and lead tetraacetate.[4] They are classical oxidants, however, they are still the reagents of choice. Although periodates effectively react with glycols in many cases, the reaction does not proceed for cyclic *trans*-glycols and ditertiary glycols. On the other hand, lead tetraacetate can react with these reactants; therefore, it has been widely used as a convenient oxidant for glycol cleavage in organic synthesis. In spite of its importance, there are some serious drawbacks of lead tetraacetate. It is highly toxic, and no less than a stoichiometric amount of reagent is required for the reaction, thus producing a large amount of toxic lead diacetate over the course of the reaction.

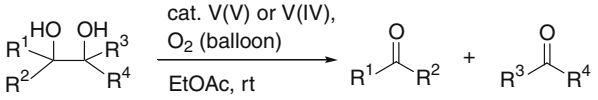
During our study of aerobic oxidation catalyzed by vanadium compounds, it was discovered that α-hydroxy ketones can be cleaved with a catalytic amount of vanadium(V) {dichloroethoxyoxyvanadium [$VO(OEt)Cl_2$] or oxytrichlorovanadium ($VOCl_3$)} under an oxygen atmosphere in alcohols.[5–7] Unfortunately, *cis*- and *trans*-cyclohexane-1,2-diols were inert under the reaction conditions. In fact, only α-cleavage was found to occur in the case of an α, β-dihydroxy ketone (Scheme 1).[5]

However, it was reported that ditertiary and secondary–tertiary glycols were successfully reacted with an equimolar amount of the dioxovanadium cation (VO_2^+) or bisacetylacetonato-oxovanadium [$VO(acac)_2$].[8] In the case of $VO(acac)_2$, the reaction proceeds catalytically in the presence of *t*-butyl hydroperoxide or *m*-chloroperbenzoic acid.[8] Therefore, we further examined the reaction of several glycols in the presence of a catalytic amount of high valent vanadiums [V(V) or V(IV)] under an oxygen atmosphere[9] and found that ditertiary glycols efficiently reacted to cause cleavage of a carbon–carbon bond in glycol (Scheme 2).

Initially, benzopinacol was treated with 5 mol % of vanadium under an oxygen atmosphere in refluxing ethanol to investigate



Scheme 1.



Scheme 2.

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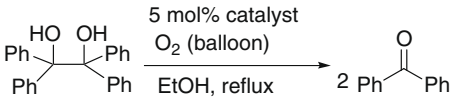
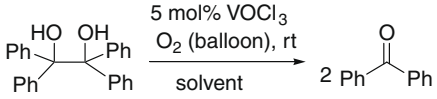
Table 1



Run	Catalyst	Time (h)	Yield (%)
1	$VO(OEt)Cl_2$	5	97
2	$VOCl_3$	14	99
3	$VOCl_2$	24	99
4	$VO(acac)_2$	24	46

Table 2



Run	Solvent	Time (h)	Yield (%)
1	MeOH	24	9
2	CH_3CN	10	90
3	AcOEt	0.5	Quant.
4[a]	AcOEt	0.5	Quant.
5[b]	AcOEt	5	Quant.
6	Toluene	24	8

[a] $VOCl_3$ (2.4 mol %) was used.
[b] $VO(OEt)Cl_2$ (5 mol %) was used instead of $VOCl_3$.

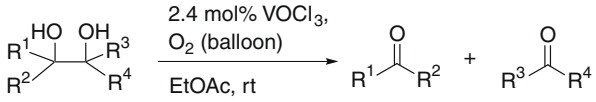
the catalytic activity of the high valent vanadium compounds toward cleavage of a ditertiary glycol (Table 1). The cleavage proceeded in all cases to produce benzophenone. The product was obtained in almost quantitative yields except for $VO(acac)_2$ (run 4).

Then, benzopinacol was treated with 5 mol % of $VOCl_3$ in a variety of solvents at room temperature under an oxygen atmosphere to evaluate any solvent effect (Table 2). As noted in run 3, ethyl acetate (AcOEt) is an excellent solvent for the oxidative cleavage. The reaction similarly proceeded with 2.4 mol % of $VOCl_3$ (run 4). Interestingly, in contrast to the reaction in refluxing ethanol, the catalytic activity of $VO(OEt)Cl_2$ is lower than that of $VOCl_3$ in room temperature AcOEt (runs 3 and 5).

The oxidative cleavage of several ditertiary glycols was examined with 2.4 mol % of $VOCl_3$ in ethyl acetate under an oxygen atmosphere at room temperature (Table 3). The corresponding ketones or diketones were obtained in moderate to high yields. With cyclic glycols, both *cis*- (entry 7) and *trans*-glycols (entries 6 and 8) similarly reacted to produce the diketones. Although the reaction mechanism is currently unknown, these results strongly suggest that the vanadium catalyst does not produce a cyclic intermediate as are the cases with periodate and lead tetraacetate. In the case of periodates, cyclic *trans*-glycols are usually inactive because it is difficult to form the cyclic intermediates.[3] Although both cyclic cis- and *trans*-glycols are active to the lead tetraacetate oxidation, cis-glycols react much faster than *trans*-glycols. In the case of the oxidation of lead tetraacetate with cyclic *cis*-glycols, the reaction proceeds through cyclic intermediates.[4]

The reaction in refluxing ethyl acetate produced a ketone in shorter reaction time (quant., 0.2 h) for a simple ditertiary glycol (benzopinacol, entry 1), however, complex mixtures were obtained in the cases of more complex diols (entries 7 and 8).

Table 3



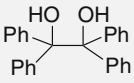
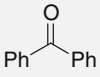
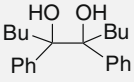
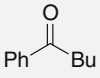
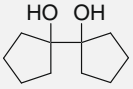
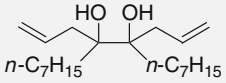
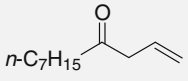
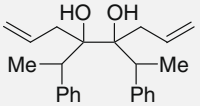
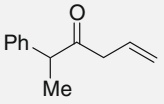
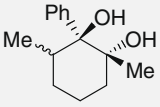
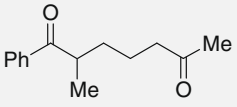
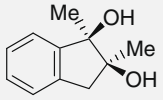
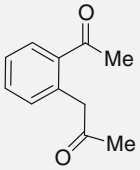
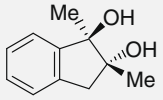
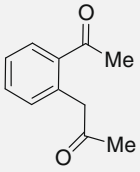
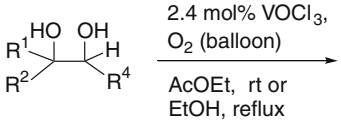
Entry	Diol	Ketone	Time (h)	Yield[a] (%)
1			0.5 0.2	Quant. Quant.[b]
2			0.5	91
3			0.5	85
4			2	74
5			3	76
6			0.5	97

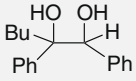
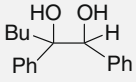
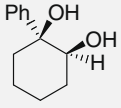
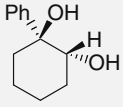
Table 3 (*continued*)

Entry	Diol	Ketone	Time (h)	Yield[a] (%)
7			8 0.5	40[c] Complex mix.[b]
8			8 0.5	60[d] Complex mix.[b]

[a] Isolated yields.
[b] Reaction in refluxing AcOEt.
[c] 2-Methyl-1-methyleneindan-2-ol (24%) was obtained as a byproduct.
[d] 2-Methyl-1-methyleneindan-2-ol (20%) was obtained as a byproduct.

Table 4



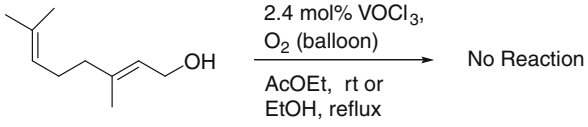
Entry	Diol	Solvent	Product
1		AcOEt	 quant.* + complex mixture
2		EtOH	 quant.* + complex mixture
3		AcOEt	Complex mixture
4		AcOEt	Complex mixture

*Based on GC analysis.

Although the reaction also proceeded for secondary–tertiary glycols, complex mixtures were obtained (Table 4). In the case of an acyclic diol (run 1), the corresponding ketone (butyl phenyl ketone) was quantitatively obtained, as part of a complex mixture. This result indicates that the tertiary alcohol portion of the reactant affords the ketone, and the secondary alcohol fragment yields complex mixtures.

This $VOCl_3$-catalyzed aerobic cleavage of a ditertiary glycol is highly chemoselective, as we previously reported.[5] Furthermore, an allyl alcohol (geraniol) was completely inert in the presence of a catalytic amount of $VOCl_3$ under an oxygen atmosphere and was quantitatively recovered (Scheme 3). This phenomenon is in sharp contrast to the $VO(acac)_2$-catalyzed oxidation in the presence of *t*-butyl hydroperoxide which produces epoxides.

In conclusion, this $VOCl_3$-catalyzed aerobic oxidation provides a pathway to the environmentally benign carbon–carbon bonds



Scheme 3.

cleavage of ditertiary glycols. Further study of the mechanism is currently underway.

A typical experimental procedure is as follows: a mixture containing the ditertiary glycol (5.0 mmol), $VOCl_3$ (11.3 μl, 0.12 mmol), and ethyl acetate (50 ml) is stirred at room temperature under an oxygen atmosphere. The reaction is monitored by thin layer chromatography (TLC). After the ditertiary glycol disappears from the TLC, the reaction is quenched with saturated aqueous sodium bicarbonate and the reaction mixture is extracted with 20 ml × 3 of ethyl acetate. The combined organic extract is washed with brine, dried over anhydrous magnesium sulfate, and evaporated. Chromatography on silica gel gives the product.

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