An Efficient and Green Oxidation of Vicinal Diols to Aldehydes Using Polymer-Supported (Diacetoxyiodo)benzene as the Oxidant

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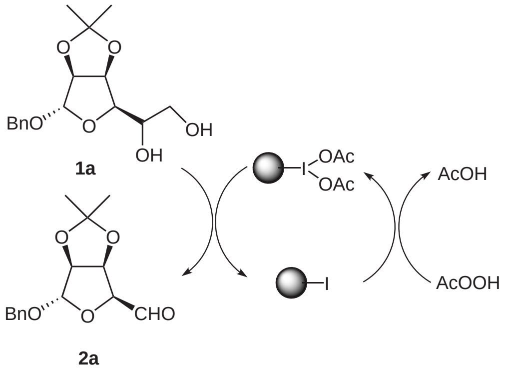
This paper is dedicated to Prof. Pei-Ling Xu on the occasion of her 80th birthday.

Abstract: An operationally simple and clean oxidation of a variety of vicinal diols to aldehydes using polymer-supported (diacetoxyiodo)benzene (PSDIB) has been developed in high to excellent yields. Protecting groups such as OAc, OR, OBn, OBz and isopropylidene in the substrates were found to be stable under these reaction conditions. The regenerated PSDIB could be reused for the same reaction, affording oxidation products in high yield and purity.

Key words: polymer-supported (diacetoxyiodo)benzene, vicinal diols, oxidative cleavage, aldehydes

It is well known that oxidative cleavage of vicinal diols using periodic acid[1] and lead tetraacetate[2] are the most classical methods for the preparation of aldehydes in organic synthesis. The use of these two highly selective oxidants is strongly restricted by periodic acid's insolubility in organic solvents, and lead tetraacetate is difficult to store and handle for large scale utilization in industry. Several oxidants, such as ceric ammonium nitrate,[3] $Ph_3Bi/NBS/K_2CO_3$,[4] CrO_3,[5] NIS,[6] thallium nitrate,[7] xenic acid,[8] ammonium chlorochromate (ACC),[9] pyridinium chlorochromate (PCC),[10] and MnO_2[11] have been reported to serve this purpose, but many of these methods still suffer from some drawbacks, including the need to employ a stoichiometric amount of reagents, long reaction time, producing a large amount of waste, and give unsatisfactory yields. Recently, an improved procedure using silica gel supported sodium metaperiodate for oxidative cleavage of vicinal glycols[12] was reported. However, the use of excess $NaIO_4$ makes this procedure impractical for industrial application. In addition, there are two reports wherein various vicinal diols were cleaved into the corresponding aldehydes with O_2-catalyzed iron–porphyrin complex[13] and $Ru(PPh_3)_3Cl/C$,[14] but the low chemoselectivity of these two oxidation systems rendered them defective. (Diacetoxyiodo)benzene was also used for oxidative cleavage of glycols forming carbonyl compounds,[15] though suffering the difficulty of removing the byproduct iodobenzene from the products. As a result, there is still room for the development of efficient, highly selective and environmentally benign methods for this transformation under mild reaction conditions from both industrial and green chemistry perspectives.

Polymer-supported hypervalent iodine reagents have been used in a wild variety of oxidation and radical reactions in organic synthesis due to their versatility, low toxicity and high reactivity.[16] The reaction products can be obtained by simple filtration to remove the polymer-supported reagent, and regeneration and reuse of the recovered polymer-supported reagents are possible, thus providing an environmentally benign system. However, to the best of our knowledge there has been no report so far describing the use of polymer-supported hypervalent iodine reagents to oxidize vicinal diols into the aldehydes. Herein, we report the successful development of an efficient, simple and synthetically useful procedure for the highly selective oxidative cleavage of vicinal diols to aldehydes using polymer-supported (diacetoxyiodo)benzene (PSDIB).



Scheme 1 Oxidative cleavage of **1a**, regeneration and recycling of used PSDIB

The PSDIB-mediated oxidative cleavage of benzyl 2,3-*O*-isopropylidene-α-D-mannofuranoside (**1a**) was initially chosen as a representative vicinal diol for the discovery of the appropriate conditions (Scheme 1). The loading of PSDIB was 1.98 mmol/g as determined by elemental analysis. We were pleased to observe that when a mixture of **1a** and 1.2 equivalents of PSDIB in CH_2Cl_2 was stirred at room temperature for seven hours, the oxidation took place smoothly and the corresponding aldehyde was successfully isolated in 90% yield (Table 1). The choice of solvents in this oxidation was crucial for the success. Acetonitrile was good for the reaction (Table 1, entry 2). The yield of **2a** dropped dramatically in the case of CH_2Cl_2–toluene mixture and reaction did not proceed at all in the toluene, THF, dioxane, acetone, or DMF.

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Table 1 Oxidation of Vicinal Diol **1a** with PSDIB in Different Solvents[a]

Entry	Solvent	Time (h)	Yield (%)[b]
1	CH_2Cl_2	7	90
2	MeCN	8.5	80
3	CH_2Cl_2–toluene (1:1)	13	43
4	toluene	50	nr[c]
5	THF	50	2
6	acetone	50	nr
7	DMF	45	nr
8	dioxane	50	nr

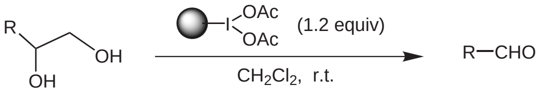
[a] All reactions were carried out according to typical procedure.
[b] Yield of isolated and fully characterized products.
[c] nr = no reaction.

Next, regeneration and recycling of the used PSDIB was investigated based on this oxidation reaction. After the first run, the polymer was recovered in almost quantitative yield by simple filtration, washed with diethyl ether. The recovered polymer was re-oxidized with peracetic acid following literature precedent[17] and the oxidations were repeated without loss of activity.

With these observations in hand, we decided to broaden its field of application by looking at the scope and limitation of this oxidation. As depicted in Table 2, all the tested substrates were smoothly oxidized into the corresponding aldehydes in excellent yields (entries 1–13). This procedure is highly chemoselective allowing oxidation of vicinal diols without affecting such functionalities as OBn (entries 1, 13), OBz (entry 2), OAc (entry 4), OR (entries 3, 9, 11), OH (entry 5), isopropylidene (entries 1–8).

In conclusion, we have developed a simple and environmentally benign protocol for the chemoselective oxidation of a range of vicinal diols into the corresponding aldehydes with high yields.[29,30] Moreover, the PSDIB consumed in this reaction can be regenerated efficiently and repeatedly used for the same reactions with no loss of activity. This procedure is characterized by mild conditions, non-toxic byproducts and easy reaction work-up, making it ideal for both laboratory and large-scale preparations.

Table 2 Oxidation of Vicinal Diols with PSDIB[a]



1 **2**

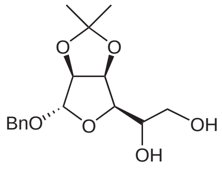
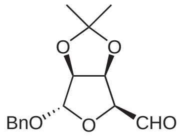
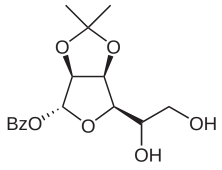
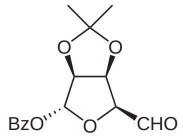
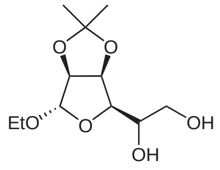
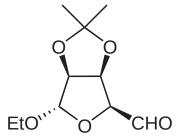
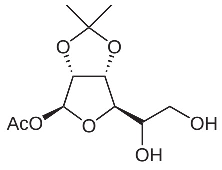
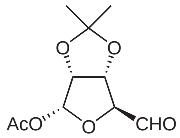
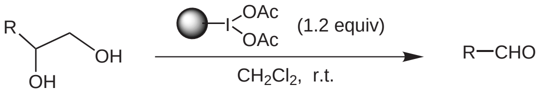
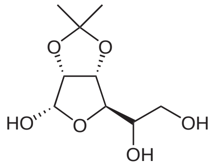
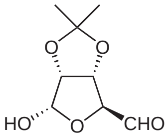
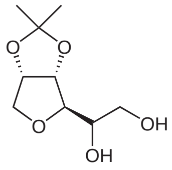
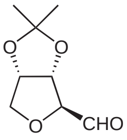
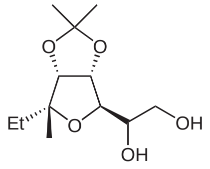
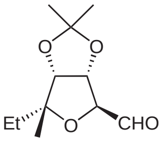
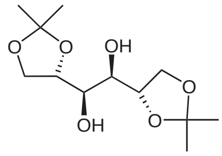
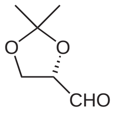
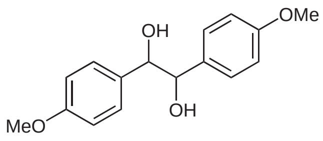
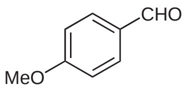
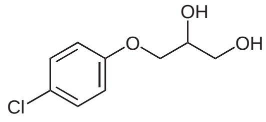
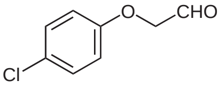
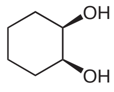
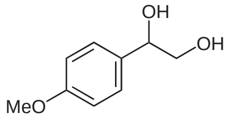
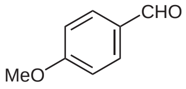
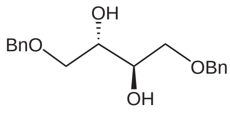
Entry	Vicinal diols	Time (h)	Products	Yield (%)[b]
1	 **1a**	7	 **2a**	90[18]
2	 **1b**	6.5	 **2b**	90[19]
3	 **1c**	7	 **2c**	85[20]
4	 **1d**	7	 **2d**	84[21]

Table 2 Oxidation of Vicinal Diols with PSDIB[a] (continued)



1 **2**

Entry	Vicinal diols	Time (h)	Products	Yield (%)[b]
5	 **1e**	7	 **2e**	82[22]
6	 **1f**	7	 **2f**	86[23]
7	 **1g**	7	 **2g**	98[24]
8	 **1h**	7	 **2h**	95[13]
9	 **1i**	7	 **2i**	91[25]
10	 **1j**	6	 **2j**	90[26]
11	 **1k**	8	 **2k**	87[27]
12	 **1l**	7	 **2l**	92[25]
13	 **1m**	7	 **2m**	92[28]

[a] All reactions were performed according to the typical procedure.

[b] Yield of isolated and fully characterized products.

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(29) **Preparation of the Polymer-Supported (Diacetoxyiodo)benzene (PSDIB).**
To a mixture of CCl_4 (20 mL), H_2SO_4 (50%, 20 mL) and nitrobenzene (100 mL) was added polystyrene (5.0 g), I_2 (5.0 g, 19.7 mmol) and I_2O_5 (4.0 g, 12 mmol) at r.t. The reaction mixture was stirred under reflux for 50 h. After cooling to r.t., MeOH (500 mL) was added into the reaction mixture. The precipitates were collected by filtration and washed with MeOH (2 × 20 mL) and dried in vacuo to afford iodinated polystyrene (6.2 g). To Ac_2O (145 mL, 1.54 mol) was added dropwise 30% H_2O_2 (40 mL, 0.35 mol) and the solution was stirred at 40 °C for 4 h. Then iodinated polystyrene (6.2 g) was added and stirring was continued overnight at the same temperature. After cooling the mixture to r.t., Et_2O (100 mL) was added into the mixture. The precipitates were collected by filtration, washed with Et_2O (2 × 20 mL) and dried in vacuo to give PSDIB (6.5 g). The loading rate of functional group is 1.98 mmol/g (determined by elemental analysis).

(30) **Oxidation of 1a.**
To a solution of **1a** (3.1 g, 10 mmol) in CH_2Cl_2 (40 mL) was added PSDIB (6.06 g, 12 mmol). Then, the reaction mixture was stirred at r.t. for 7 h. Thereafter, the polymer was filtered and washed with CH_2Cl_2 (3 × 8 mL). The filtrate was poured into H_2O (45 mL), and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic layer was washed with H_2O (3 × 10 mL), dried over Na_2SO_4, filtered, and the solvent was evaporated in vacuo to give crude product, which was recrystallized from PE (60–90) to afford pure **2a** (2.5 g, 90%) as a white powder; mp 81.5–83 °C; $[\alpha]_D^{25}$ +28.2 (*c* 1.0, acetone). IR (KBr): ν = 2935, 1750, 1361, 749 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.26, 1.40 (s, each 3 H, *i*-Pr), 4.42 (d, 1 H, J = 4 Hz, C_3-H), 4.49 (d, J = 1 H, 12 Hz, C_2-H), 4.67 (t, 2 H, J = 5.6 Hz, $CH_2C_6H_5$), 5.07 (dd, 1 H, J = 4.8, 5.6 Hz, C_4-H), 5.27 (s, 1 H, C_1-H), 7.26–7.35 (m, 5 H, ArH), 9.65 (s, 1 H, CHO). GCMS: m/z (%) = 263 $[M – CH_3]^+$, 187, 129, 113, 91 (100).