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Reliability of assigning O–H · · · O hydrogen bonds to short intermolecular O · · · O separations in cyclodextrin and oligosaccharide crystal structures: addendum [☆]

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Abstract

Addendum to the previous study [*Carbohydr. Res.*, 259 (1994) 1–12], to show that C–O · · · O coordination angles are not a useful criterion for the identification of hydrogen bonds if the H-atom positions are not known.

Keywords: Hydrogen bonding; Cyclodextrin; Oligosaccharide; Crystal structures

1. Introduction

If in crystal structures of cyclomalto-oligosaccharides (cyclodextrins, CDs) H-atoms cannot be located from X-ray data, O–H · · · O hydrogen bonds are tentatively assigned on the basis of short O · · · O contacts. Recently, we have discussed the reliability of this procedure by describing the statistical relation between O · · · O separations and hydrogen bonding in six cyclodextrin neutron diffraction studies, in which all H-atom positions were determined [1]. We came to the conclusion that, provided the O positions are accurately determined, intermolecular O · · · O separations shorter than 3.0 Å can be interpreted as hydrogen bonds with near certainty, and O · · · O separations > 3.6 Å indicate absence of hydrogen bonding also with near certainty. In the distance region

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[☆] Topography of Cyclodextrin Inclusion Complexes, Part 33. For Part 32, see Ref. 1.

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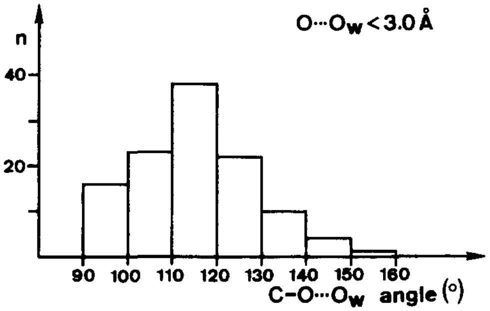

Fig. 1. Distribution of C–O · · · O_W angles for contacts of hydroxyl groups to water molecules with O · · · O < 3.0 Å (data set as in Ref. 1). *All* these contacts are hydrogen bonds.

3.0–3.6 Å, the probability for hydrogen bonding smoothly decreases with increasing O · · · O distance.

Occasionally, coordination angles are used as an additional criterion for the assignment of O–H · · · O hydrogen bonds to O · · · O contacts. Due to the softness of these angles, this was avoided in the previous study without further justification. In this addendum, a brief discussion of the matter is given, based on the same data set.

2. Results

In the data set, *all* intermolecular O · · · O contacts < 3.0 Å are hydrogen bonds [1]. The distribution of the corresponding C–O · · · O angles is shown for the simplest case, which are the contacts from hydroxyl groups to water molecules (O_W), in Fig. 1. Even for these shortest contacts, the preference for tetrahedral angles (109°) is very soft, with values in the range 90° to > 150°.

Longer O · · · O separations between 3.0 and 3.6 Å can be interpreted as hydrogen bonds only with limited reliability and it would be desirable to have suitable additional criteria supporting the assignment. To test the power of C–O · · · O angles to identify hydrogen bonds with critical O · · · O distances 3.0–3.6 Å, the relation between these angles and hydrogen bonding is described for contacts of hydroxyl groups to water molecules in Table 1. Despite the small number of data, it becomes clear that the C–O · · · O_W angle is not suitable to identify hydrogen bonds. At angles around 110°, which are preferred for hydrogen bonds, numerous van der Waals contacts are also observed, e.g., the contact O-6^6 · · · W-4, 3.15 Å, with C–O · · · O_W = 106.5°, shown in Fig. 2A in ref. 1. On the other hand, there are some hydrogen bonds with very large deviations from tetrahedral angles.

For contacts between hydroxyl groups and for contacts to the glycosidic oxygen atoms O-4 and O-5, the situation is geometrically more complex, because there is more than one independent C–O · · · O angle. Here, hydrogen bonds are also often considerably distorted from tetrahedral geometry: in hydrogen bonding C–O · · · O–C contacts, frequently both C–O · · · O angles deviate more than ±20°, and sometimes even more

Table 1

Contacts of hydroxyl groups to water molecules with O · · · O between 3.0 and 3.6 Å

C–O · · · O_W angle (deg.)	$n_{O \cdots O}$ [a]	n_{H-bond} [b]	Fraction of H-bonds [c]
70– 90	3	2	0.6
90–110	13	7	0.5
110–130	8	5	0.6
130–150	2	1	0.5
150–170	4	2	0.5

[a] Number of C–O · · · O_W contacts in the given angular range.

[b] Number of C–O · · · O_W contacts which are associated with a hydrogen bond.

[c] Fraction of the O · · · O contacts which represent hydrogen bonds. Due to the small number of data, a standard error cannot be reasonably estimated.

than ± 30°, from 110°. As for the contacts C–O · · · O_W, this indicates that C–O · · · O coordination angles should not be used as a hydrogen bond criterion.

The results given above and in Ref. 1 are valid only if the experimental error of the O · · · O distances is small compared to the step-width 0.1 Å of the relevant histograms. If the errors of the O positions are around or larger than 0.1 Å, which is not unusual with poorly resolved disorder of O atoms and normal even for high resolution macromolecular structures, additional uncertainty in the assignment of hydrogen bonds is introduced.

References

[1] Th. Steiner and W. Saenger, *Carbohydr. Res.*, 259 (1994) 1–12.