Supporting information

Photodegradable iron(III) cross-linked alginate gels

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Preparation of iron(III) cross-linked alginate beads. 1% w/v alginate solution was added dropwise by a syringe with a 19 gauge needle to 1% w/v aqueous solution of iron(III) chloride under gentle stirring. The beads were kept in the iron solution for 15 minutes for cross-linking before being washed twice with distilled water. The obtained yellow-brown nearly spherical beads were then kept in distilled water at room temperature for 3-5 days before reductions experiments.

The experiment produced 100 beads, Based of sample of ten beads the of beads diameter was 2.46 ± 0.07 mm and weight was 8.1 ± 0.5 mg
The obtained beads are mechanically stable. After 24 h of swelling in distilled water the average weight increased from 8.1 mg to 8.4 mg, and 24 h of swelling in 0.9% sodium chloride solution the average weight changed from 8.1 mg to 8.7 mg.

Image of iron(III) cross-linked alginate beads. The average bead diameter is 2.46 mm.

Reductive dissolution of iron(III) cross-linked alginate beads with ascorbate and glutathione.

To study degradation of iron(III) cross-linked alginate by reducing agents used two endogenous reducing agents ascorbic acid ($E^{\circ} + 58\, mV$ at pH 7.0) and glutathione ($E^{\circ} -230\, mV$ at pH 7.0) that are both capable of irreversible reduction of iron(III) cations at ($E^{\circ} + 771\, mV$ at pH 7.0). The obtained iron(III) cross-linked beads were treated with a large excess of 2-10 mM solution of sodium ascorbate in pH 7.4 MOPS buffer.

The treatment was followed by relatively rapid disintegration of alginate beads into smaller fragments followed by slower complete dissolution of these fragments. The rapid disintegration of beads is likely to be the result of heterogeneity of alginate beads caused by immediate gelation of alginate by iron(III) cations. Relatively slow rates of complete iron(III) alginate beads dissolution in comparison to rapid reduction of iron(III) cations by ascorbic acid in the solution phase can be attributed to slow diffusion of reducing agents through the cross-linked alginate gel. As a result, the dissolution of alginate bead takes place in a shallow layer near the surface of
beads rather than in the volume of beads. Very similar results were obtained through reduction of iron(III) cross-linked alginate beads with glutathione. In both cases rates of dissolution strongly depended on concentration of reducing agent. At low concentrations of ascorbate and glutathione (2 mM) beads were stable for long time. Increased concentration of reductants resulted in almost instantaneous breaking of beads followed by complete dissolution of broken beads in less than 30 min.

Table 1. Breakup and dissolution of iron(III) cross-linked alginate beads in pH 7.0 20 mM MOPS buffer in the presence of ascorbic acid and glutathione in 20 mM.

<table>
<thead>
<tr>
<th>Reducing agent</th>
<th>T\text{\break}</th>
<th>T\text{\dissolution}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mM ascorbate</td>
<td>&gt; 24 h</td>
<td>&gt; 24 h.</td>
</tr>
<tr>
<td>10 mM</td>
<td>60 min</td>
<td>12 h</td>
</tr>
<tr>
<td>20 mM ascorbate</td>
<td>1 min.</td>
<td>16.5 min.</td>
</tr>
<tr>
<td>40 mM ascorbate</td>
<td>~ 30 seconds</td>
<td>8.8 min.</td>
</tr>
<tr>
<td>2 mM</td>
<td>&gt; 24 h</td>
<td>&gt; 24 h.</td>
</tr>
<tr>
<td>5 mM</td>
<td>2 min.</td>
<td>104 min.</td>
</tr>
<tr>
<td>10 mM</td>
<td>2 sec.</td>
<td>28.7 min.</td>
</tr>
</tbody>
</table>

2.3. Photoinduced dissolution of iron(III) cross-linked alginate beads. A suspension of 50 of iron(III) cross-linked alginate beads prepared according to procedure above in 100 mL of solution containing 20 mM of sodium lactate with pH adjusted to pH 7.0 was irradiated with a fluorescent 365 nm UVA lamp having a light intensity of 2.73 mW/cm². During the irradiation process samples containing 5 beads were taken for measurement of average diameter.
Dependence of average bead diameter from irradiation time is shown on Figure 1 below. After 60 min of irradiation all beads were completely dissolved.

![Figure 1. Change of average bead diameter during photoinduced dissolution in 20 mM pH 7.0 sodium lactate under 365 nm UV irradiation 2.73 mW/cm².](image)

**Comparison of preparation of iron(III) cross-linked gel by air oxidation of iron(II) alginate solution using different sources of sodium alginate.**

Because composition and molecular weight of sodium alginate from different sources can affect on production of gels we compared sodium alginate from brown algae: Sample A (Sigma, catalog number 71238, Lot #BCBD1103V), Sample B (Sigma, medium viscosity, catalog number A2033, Lot #108K1228V), Sample C (Sigma, medium viscosity, catalog number A2033, Lot #035K0204), Sample D (Sigma, low viscosity, catalog number A2158, Lot #090M0092V), and Sample E (FMC BioPolymer, catalog number FP504-03). All of these samples of sodium
alginate successfully produced beads in a solution of iron(III) chloride. However, different results were obtained with air oxidation of iron(II) alginate. While Samples A and E indeed provided formation of the iron(III) cross-linked gel using the standard procedure, samples C and D failed to produce gel within 24 h under these conditions (1% w/w sodium alginate, 20 mmol/L iron(II) chloride, 20 mmol/L sodium lactate), and the gel was produced only if concentrations of iron(II) chloride is increased from 20 to 30 mmol/L. Sample B of sodium alginate did not produce gel even with 30 mmol/L concentration of iron(II) chloride.

**Statistical treatment of results on Figures 2, 3, 4, and 6.**

Figure 2. The obtained graph of dependence of optical density at 508 nm from irradiation time was linearly fitted using LINEST subroutine of MS Excel giving $r^2=0.972$ for butyric, $r^2=0.972$ for methoxyacetic, $r^2=0.914$ for formic, $r^2=0.9995$ for malic, and $r^2=0.985$ for lactic acid. Error bar equal to the calculated standard error for the y estimate were added to the trend line.

Figure 3. Relative rates of photoreduction were calculated based on results described on Figure 2. Error bars corresponding to calculated standard error for the y estimate multiplied on the relative rate of photoreduction were added.

Figure 4. The obtained graph of dependence of optical density at 540 nm from irradiation time was linearly fitted using LINEST subroutine of MS Excel for all data obtained before the complete dissolution of beads (2-36 min.) to give $r^2=0.997$. Error bar equal to the calculated standard error for the y estimate were added to the trend line.

Figure 6. The obtained graphs of dependence of time required for complete dissolution from gel thickness were fitted using LINEST subroutine of MS Excel giving $r^2=0.982$ for the lower
trend line, and \( r^2 = 0.998 \) for the upper line. Error bar equal to the calculated standard error for the y estimate were added to the trend line.