Smart Materials in Dentistry – How Smart is Smart?

Dr Matthew German
Prof. John McCabe
Traditional Direct Filling Materials

- Return form and function
- Inert = long lasting
- Failures
- New developments needed
Future Trends in Dental Materials

- Refinement of existing technologies
  - Better composites, bonding agents
- Tissue engineering solutions
  - Scaffolds
  - Stem cells
- Nanotechnology
- Smart materials
What are Smart Materials?

• Materials possess a type of ‘smart’ behaviour if they can interact with their environment to produce an outcome which is beneficial to their function.

• Some dental materials may be identified as ‘smart’ materials for the unique way in which they react to the oral environment, e.g. moisture, pH, bacteria and temperature changes, etc.
Smart Materials

- Chromogenic systems
  - electrochromic
  - thermochromic
  - photochromic
- Piezoelectric materials
- Shape Memory materials
  - Metal – NiTi
  - Polymers – p(NIPAAm)
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Figure 1. Schematic figure of the different types of responses of “intelligent” polymer systems to environmental stimuli.\textsuperscript{3}

Pre-requisites for Smart behaviour

• Material interacts with environment
  • Stimulated by changes in ambient conditions

• Some reactivity essential
  • But must not destroy integrity

• Any reaction must be reversible or time limiting
  • Function/longevity of the material must be acceptable

• Inert materials cannot be smart
  • Traditional approaches to materials development are inappropriate for ‘smart’ behaviour
Smart Potential May Be Demonstrated By:

- Contain fluid (e.g. water) which can equilibrate with environment
- Have reactivity which is pH dependent
- Have leachable ingredients which can be replenished
- Can be stimulated by a temperature change
Existing Dental Materials With ‘Smart Potential’

- GICs
  - Salt matrix
  - Contain water
- RMGICs
  - Salt and resin matrix
  - Absorb water
- HEMA containing resins
  - Gel and resin matrix
  - Absorb water
Experiments with GICs and RMGICs

- Thermal expansion and contraction
- Fluoride release and recharging
  - Classic ‘smart’ behaviour
- Influence of porosity
  - Can this be controlled?
  - Role in ‘smart’ behaviour
- Biofilms and smart behaviour
Thermal Behaviour of Direct Filling Materials

- Oral temperature 5-70°C
- Coefficient of thermal expansion
- Mismatch between filling material and tooth structures

<table>
<thead>
<tr>
<th>Material</th>
<th>°C⁻¹ x 10⁻⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>11.4</td>
</tr>
<tr>
<td>Dentine</td>
<td>8</td>
</tr>
<tr>
<td>Acrylic resin</td>
<td>90</td>
</tr>
<tr>
<td>Amalgam</td>
<td>25</td>
</tr>
<tr>
<td>Composite resin</td>
<td>25-60</td>
</tr>
</tbody>
</table>
Thermal Expansion Measurement

Quartz probe and support

Sample in ambient air

Load

Probe

Furnace

Support

Sample

Wet cotton

Newcastle University
Thermal Behaviour of Human Dentine

![Graph showing dimensional change vs temperature for dry and wet dentine.](image)
Thermal Behaviour of Filling Materials

- Synergy - PRC
- Fuji II LC – RMGIC
- Ketac-Cem
- Ketac-Molar \{ GIC \}
- Fuji IX
• Resin matrix materials expand on heating in both dry and wet conditions
• HEMA containing materials contract on heating in dry conditions and expand in wet conditions
• Salt based materials (e.g. GICs) show little or no dimensional change between 20-55°C in dry or wet conditions
Fluoride Release of Glass Ionomers

- Potential beneficial effects of fluoride release
- GICs have negligible release rates within a week
- Daily fluoride re-charging
- Recharging in fluoride solution allows sustained release
Temperature and Re-charging

- Fluoride release and re-charging is temperature dependent
- High uptake at high temperature
- Sustained re-release at mouth temperature
• Control of composition and structure to produce a desired effect
  • Control resin matrix
    • Hydrophobic/hydrophilic
  • Control resin/salt ratio
    • Composition
    • Setting characteristics
• Control porosity
  • Mixing
The Role of Porosity

- Can porosity act as sites for water reservoirs?
  - Does this affect rate of flow of water?
  - Does this affect total water retained?
- Can porosity be controlled?
  - Composition
  - Viscosity
  - Mixing
Effect of Porosity

• 2 Different GICs
  • Ketac-Molar and Ketac-Cem
• 3 mixing techniques
  • Shaking, rotating, hand
• Micro-CT measure for porosity
• Compressive Strength
X-ray Image and Section Images

Z axis

X axis

Y axis
3-D Reconstruction

Ketac-Cem

CapMix  RotoMix  Hand

Ketac-Molar

CapMix  RotoMix  Hand
### Total volume ratio of bubbles (Vol%)

<table>
<thead>
<tr>
<th>Material</th>
<th>Mixing method</th>
<th>Ketac-Cem (Maxicap)</th>
<th>Ketac-Molar (Aplicap)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capmix (Shaking)</td>
<td>2.7 (2.6)</td>
<td>0.2 (0.2)</td>
</tr>
<tr>
<td></td>
<td>RotoMix (Rotating)</td>
<td>2.1 (2.1)</td>
<td>0.1 (0.1)</td>
</tr>
<tr>
<td></td>
<td>Hand</td>
<td>0.2 (0.2)</td>
<td>0.1 (0.1)</td>
</tr>
</tbody>
</table>

- For Ketac-Cem, the porosity of encapsulated specimens was significantly greater than the hand-mixed specimens.
- For Ketac-Molar, there was only a small difference in the total volume ratio of bubbles among the specimens mixed by different methods.

Compressive Strength of Cements

- Capmix
- RotoMix
- Hand

![Graph showing compressive strength of Ketac-Cem and Ketac-Molar](image)

Summary of porosity findings

• The difference between Ketac-Cem and Ketac-Molar is due to the difference in consistency
• A lower consistency material (Ketac-Cem) encourages the generation of more bubbles during mechanical mixing
• Hand mixing lowers porosity
## Porosity and Water Sorption
### Ketac-Cem – Capmix and Hand Mix

<table>
<thead>
<tr>
<th>Mixing</th>
<th>porosity [%]</th>
<th>24h water sorption [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capmix</td>
<td>2.7 (2.6)</td>
<td>1.32 (0.25)</td>
</tr>
<tr>
<td>Hand</td>
<td>0.2 (0.2)</td>
<td>0.84 (0.11)</td>
</tr>
</tbody>
</table>
Smart Behaviour and Biofilms

- Live (green), dead (red) staining of bacteria observed with CLSM
- Fluoride release does not prevent biofilm formation
- Biofilm may alter rate of fluoride release

Image of biofilm on surface of GIC shown by live/dead method
Patterns of Fluoride Release - 24h Values

Effect of biofilm

- Distilled Water
- Artificial Saliva
- Natural Saliva

- Acidified
- A & N
- Non-Acidified
- N & A
Effect of Biofilm on Wear of GIC
Biofilm Prevents Wear

20 μm

Baseline

After 200K brushing cycles

In acidified natural saliva

After 200K brushing cycles

In acidified artificial saliva
Smart behaviour and biofilms

- Biofilm concentrates fluoride
- Biofilm protects from wear
- Acid conditions alter biofilm
  - Fluoride ‘burst’

Image of biofilm on surface of GIC shown by live/dead method
The “Smart Cycle”

Surface covered with biofilm

Biofilm protects surface and stores fluoride

Acid alters biofilm and releases stored fluoride
Components of a Smart Dental Material

- **Resin** – creates stability, controls setting
- **Salt phase** – allows water capture
- **Glass Filler** – reinforces and provides ions
- **Water** – allows a reaction to a stimulus
- **Porosity** – creates reservoirs
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