Short Communication

Potential of pure cellulose nanofibers as a denture base material

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Abstract: A study was conducted to evaluate the basic mechanical properties of a pure cellulose nanofiber (CNF) material in comparison with a commercial denture base material (polymethylmethacrylate [PMMA] acrylic resin). The working hypothesis was that CNFs have potential for use as denture base materials. Pure CNF specimens fabricated under various conditions were examined. The flexural strength (FS) and flexural modulus (FM) of the specimens were measured using the three-point bending test, and the morphologies of the fractured surfaces were examined using scanning electron microscopy. Addition of tricalcium phosphate to dehydrate the CNFs did not improve their FS or FM. Conversely, substitution with methanol effectively improved the dehydration process and significantly affected the mechanical properties of the CNFs. As the degree of CNF defibration increased, the physical properties of the specimens improved significantly. However, addition of CNFs to PMMA liquid to create CNF-reinforced PMMA did not improve the mechanical properties. Pure CNF specimens fabricated under particular conditions had higher FS and FM values than the control, suggesting that CNFs have potential as a “petroleum-free” alternative to acrylic resin denture base materials. Pure CNF would be potentially useful as a denture base material, and presumably applicable to computer-aided design/manufacture (CAD/CAM).

Materials and Methods

Pure CNFs (Nanoforest; Chuetsu Pulp & Paper, Takaoka, Japan) were used in the present study. CNF samples were manufactured by: (1) dehydrating an aqueous solution of CNFs; (2) pressurization; and (3) drying. Increasing the degree of dehydration improves the physical properties of a CNF sample, but requires considerable time and effort.

Effect of defibration degree and methanol substitution on mechanical properties

Effect of defibration degree on the mechanical properties of CNF specimens

Defibration is a machine treatment in which pulp fiber is crushed in water to make it finer (1-time process = 1 pass). CNF samples with three different degrees of defibration were prepared (5, 15, and 50 passes). Also the effect of another dehydration treatment using methanol was examined. To enhance the efficacy of dehydration, the aqueous CNF solution was subjected to solvent substitution using methanol. After replacement with the solvent, CNF specimens were fabricated following the same pressurization, drying, and cutting processes described above.

Effect of defibration degree and methanol substitution on mechanical properties

TCP was added to the aqueous CNF solution at concentrations of 0%, 5%, and 10% to accelerate dehydration. After the dehydration process, each specimen underwent pressurization and drying, and a 3-mm-thick CNF plate was fabricated. A cutting disc and dental micromotor were used to cut each specimen (0%, 5%, and 10% TCP) into a plate measuring 64 mm × 10 mm × 3 mm. A heat-polymerized acrylic resin (Acron; GC, Tokyo, Japan) was used as a control.

Effect of CNF reinforcement on the mechanical properties of PMMA-based denture base resin

To determine the reinforcing effect of CNFs, specimens comprising PMMA powder (Acron; GC) and a liquid phase comprising a methylmethacrylate monomer with various CNF concentrations (ranging from 0.1% to 5%) were prepared. The mechanical properties of the test specimens were then compared with the control specimen (without CNFs).

Evaluation method

Five specimens from each group were used for the evaluations described below (Fig. 1a, 1b). The flexural strength (FS) and flexural modulus (FM) of the specimens (size: 64 mm × 10 mm × 3 mm) were measured by applying a three-point bending test using the conditions of the ISO20795-1 standard. For this purpose, a universal testing machine (model 5565;Instron, Canton, MA, USA) with a crosshead speed of 5.0 mm/min and a 2-kN load cell (serial number: UK268) was used. The FM (E) values were calculated using the following equation:

\[ E = \frac{F_l}{4bh^3d} \]

where \( F_l \) is the load at a point on the straight-line portion of the load/deflection curve (at the maximum slope), \( l \) is the distance between the supports (50.0 mm), \( b \) is the width of the specimen (10.0 mm), \( h \) is the height of the specimen (3.0 mm), and \( d \) is the deflection under the \( F_l \) load.

Keywords; cellulose nanofiber, denture base material, polymethylmethacrylate
The FS(δ) values were calculated using the following equation:

\[
\delta = \frac{3F}{2bh^2}, \tag{2}
\]

where F is the maximum load during the flexural test.

The morphologies of the fractured surfaces were examined using a scanning electron microscope (JSM-6390LA; JEOL Ltd., Tokyo, Japan).

Analysis of variance and the Tukey HSD test were used for statistical analysis of the basic mechanical properties (\(\alpha = 0.05\)). One-way analysis of variance followed by Dunnett’s test was used to analyze the data for CNF reinforcement. The comparison data met the criteria for a normal distribution and homogeneity of variance (\(P > 0.05\); Kolmogorov-Smirnov test and homoscedasticity test). Statistical analyses were conducted using SPSS version 21.0 (SPSS Inc., Chicago, IL, USA).

Results

The three-point bending test showed that pure CNF samples produced without addition of TCP had significantly higher FS and FM values than the control sample (Fig. 1a, 1b).

The FS values were significantly higher in the methanol-substituted group than in the non-methanol-substituted group (Fig. 2a). The specimens prepared with 15- and 50-pass defibration had significantly better mechanical properties than those prepared with 5-pass defibration (Fig. 2a). The FM values did not differ significantly between the groups (Fig. 2b).

All of the specimens containing CNFs had significantly lower FS values than the control acrylic resin (Fig. 3a). The materials comprising 1%, 3%, and 5% CNFs had significantly higher FM values than the control acrylic resin (Fig. 3b). The specimens comprising 5% CNFs had rough surfaces (Fig. 3c).

Discussion

The present study revealed that specimens of pure CNF had higher FS and FM values than the control, suggesting that CNFs could be potentially useful as denture base materials.

TCP added to accelerate the dehydration of the raw CNFs during the fabrication process degraded the mechanical properties, and did not create a reinforcement effect via chemical bonding with the CNFs. As described in the Methods section, the physical properties of the CNF samples are improved by stronger dehydration; however, this process requires considerable time and effort. Therefore, TCP was added in an attempt to accelerate the dehydration process, which reduced the time required for dehydration. Although in detail chemical reaction between the CNFs and TCP was not evaluated, addition of the latter may have decreased the connections between CNFs. Scanning electron microscopy revealed some crystals in
the CNF samples with TCP, but not in those without TCP. The density of the samples with TCP was slightly decreased.

Conversely, methanol substitution effectively improved the dehydration process and the mechanical properties of the materials. The physical properties of the CNFs improved as the degree of defibration increased. Within the limitations of the present study, these results suggest the potential of CNFs as denture base materials that could be amenable to CAD/CAM. However, CNF-reinforced PMMA did not seem useful in this respect, as addition of CNF led to a reduction in mechanical strength. This suggests that the fibers are distributed in the polymerized resin, thus decreasing the density of the firm polymer. Further research is required to evaluate CNF-reinforced PMMA.

In conclusion, CNFs have potential as a “petroleum-free” alternative to acrylic resin-based dental materials.

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Conflict of interest
The authors have no conflict of interest to declare.

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