Computed Tomographic Evaluation of Bone Quality of the Mandible Reconstructed by Particular Cellular Bone and Marrow Combined with Platelet Rich Plasma

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Abstract: Concerning the bone structures of the mandible reconstructed by particular cellular bone and marrow (PCBM), platelet rich plasma (PRP) and tray, we have examined the possibility of implant insertion by clarifying the morphological conditions in each compact and cancellous bone on computed tomography (CT), and by observing the differences in their CT values.

Using the computer software program Sim Plant (Materialize Dental, Leuven, Belgium), we morphologically observed 6 cases of implant inserted area after mandibular reconstruction and 11 cases of native bone, and examined the differences in their CT values. The osseointegration rate of each inserted implant was also evaluated.

Compared with the native bone group, the PCBM reconstruction group had generally thin compact bone. In the over-3 cm-length PCBM reconstruction group, the average CT value was 259.7 ± 94.4 HU (n = 3) in the cancellous bone, whereas in the native bone group, the average CT value was 528.9 ± 140.1 HU (n = 10). Therefore, the PCBM reconstruction group showed significantly lower CT value than the native bone group. However, in the under-3 cm-length group, the PCBM reconstruction group showed no significant difference compared with the native bone group. The osseointegration rate of the inserted implants almost 6 months after insertion was 100% in the PCBM reconstruction group and 94.1% in the native bone group.

Although the PCBM reconstructed bone had thinner cortical bone and showed lower CT value compared with the native bone, implant insertion was possible.

Key words: mandibular reconstruction, platelet rich plasma (PRP), particulate cancellous bone and marrow (PCBM), bone quality, Hounsfield unit (HU)

Introduction

There are various methods for mandibular reconstruction, but no consensus has been reached on the definitive method. Vascularized free bone grafts and filling particular cellular bone and marrow (PCBM) into a titanium tray are considered to yield excellent results¹. The latter method, which
was first reported in 1970\textsuperscript{2}, has many advantages, such as its far lower invasiveness to the recipient bed compared with vascularized free bone grafts, and also its ease of obtaining a suitable contour, which is favorable for continuing functional oral rehabilitation using implants\textsuperscript{1}. The recently established PCBM harvesting method from the posterior iliac crest makes it possible to secure sufficient amounts of bone\textsuperscript{3}, and the combination with platelet rich plasma (PRP) further promotes bone formation and wound healing\textsuperscript{4}. At our department we frequently use the PCBM reconstruction method for mandible reconstruction of defects within 10 cm\textsuperscript{5}. However, in spite of the formation of clinically sufficient amounts of bone, in many cases its opacity differs from that of the surrounding bone even one year after the operation\textsuperscript{5}. Marx \textit{et al.} reported the same findings\textsuperscript{6}. If the bone quality is poor, osseointegration is highly likely to fail, and there is a risk of fractures due to long-term bone resorption or lack of bone strength. In an extensive review of the literature, however, reports evaluating bone quality after the PCBM reconstruction were not found.

Regarding the bone structure in cases of inserted implants after mandible reconstruction with PCBM + PRP + tray at our department, we have examined the possibility of implant insertion by evaluating the morphological changes and their Hounsfield Unit (HU) in each compact and cancellous bone on computed tomography (CT). We also comparatively examined HU in cases of implants inserted into the native bone as controls.

\textbf{Materials and methods}

\textbf{1. Cases}

We studied 6 cases of inserted implants after mandibular reconstruction or alveolar bone augmentation using PCBM + PRP + tray at Tokyo Medical University Hospital (PCBM reconstruction group). As controls, we studied 10 cases of previously inserted implants in the native bone (native bone group), and 1 case of the reconstruction group in which an implant was inserted in the native bone on the other side (Table 1).

\begin{table}[h]
\centering
\begin{tabular}{cccccc}
\hline
\textbf{Case} & \textbf{Sex} & \textbf{Age} & \textbf{Site} & \textbf{Primary disease} & \textbf{PRP harvest amount (ml)} & \textbf{Approach} & \textbf{Reconstructed length (cm)} \\
\hline
1 & M & 20 & trauma & & 60 & intra-oral & 13.9 \\
2 & F & 57 & ameloblastoma & & 60 & intra-oral & 30.4 \\
3 & F & 30 & follicular cyst & & 20 & intra-oral & 14.1 \\
4 & M & 31 & trauma & & 20 & extra-oral & 16.3 \\
5 & F & 38 & ameloblastoma & & 60 & intra-oral & 42.8 \\
6 & M & 60 & osteomyelitis & & 60 & extra-oral & 65.5 \\
\hline
\end{tabular}
\caption{Cases}
\end{table}

Six cases of inserted implants after mandibular reconstruction or alveolar bone augmentation using PCBM + PRP + tray. The reconstructed length is the maximum length between the medial and distal ends.
2. Surgical procedure

Immediately before surgery, 40-60 ml of venous blood was collected to produce PRP and autologous thrombin. PRP was separated using an exclusive centrifuge, Smart Prep System (Harvest Technologies Corp., Norwell, MA, USA). The centrifuge was programmed for an initial spin of 2500 rpm for 10 minutes, a 1-minute interval, and an additional spin of 2300 rpm for 3 minutes. The first step of the surgical procedure was PCBM harvesting, from the posterior iliac crest when only a small amount of bone was needed, and from the bilateral posterior iliac crest when the defect was so large as to need a larger amount of bone. The next step was to adapt a titanium mesh tray to the defect after mandibulectomy. The harvested PCBM, the separated PRP, and the autologous thrombin were mixed in a Petri dish and left for a while to become platelet gel, which was closely filled between the remaining mandible and the tray (Fig. 1). The last step was to fix the tray rigidly with screws and close the wound (Fig. 2a, 2b).

Postoperatively, implants were inserted on removal of the tray in one case, and the tray was removed 5 to 6 months after reconstruction and implants were inserted 8 to 14 months after reconstruction in the other cases. The two-time operation method was adopted for implant treatment in all cases, and the re-entry was performed after 6 months (Fig. 2).

3. Examination methods

1) Postoperative infection and gingival condition

Postoperative infection cases were marked (+) and non-infection cases were marked (−). Regarding the gingival condition, cases in which there was an increase in attached gingiva were marked (+) and those in which there was no increase were marked (−).

2) Macroscopic observation of bone formation

The macroscopic condition of bone formation was examined visually and on palpation. Cases in which bone formation was not clearly seen were marked (−). Cases in which bone formation was seen but over a smaller area, or in which bone hardness did not amount to that of native bone on palpation, were marked (+). Cases in which bone formation was seen and the hardness was equal to that of native bone were marked (−).

3) Observation of bone formation on panoramic tomography

After removing the tray, we examined the bone formation on orthopantomography performed before implant insertion. Cases in which the bone opacity was clearly far lower than that of the native bone were marked (−), cases in which the
bone opacity was close to that of the native bone but still lower were marked (+), and cases in which the bone opacity was equal or nearly equal to that of the native bone were marked (++).

4) Examination on CT

We used CT data taken before implant insertion. We scanned CT images at a slice thickness of 1.25 mm using a Light Speed Ultra (General Electric Company, Fairfield, CT, USA). We analyzed DICOM data of the tomogram using the computer software program Sim Plant (Materialize Dental, Leuven, Belgium).

a) Morphological analysis: We observed the compact and cancellous bone structures of implanted parts on buccolingual, axial, and panoramic view images (PCBM reconstruction group: 13 parts in 6 cases, native bone group: 17 parts in 11 cases). We evaluated the compact bone thickness on buccolingual view images as thicker, almost the same, or thinner than that on the opposite side in each case.

b) CT value. We selected two different areas in the implanted part, both in the PCBM reconstruction group and in the native bone group, and measured the CT value (Fig. 3). In one condition, we selected the Volume of Interest (VOI) of 3.5 mm diameter × 10 mm length at the implanted part including the compact and cancellous bone, and measured the CT value. The obtained CT value was classified according to Misch criteria7 (Table 2). In the other condition, we selected the same size of VOI limited to the cancellous bone directly under the compact bone, and measured the CT value in the same manner. In one case, implants were inserted in the PCBM reconstructed bone on one side, and in the native bone on the other side, and we compared their CT values. Furthermore, after measuring the reconstructed length on CT we divided the PCBM reconstruction group into two groups: 3 cases (4 parts) of under 3 cm in length, and 3 cases (9 parts) of over 3 cm in length, and compared their CT values.

5) Evaluation of the implant osseointegrated rate

We evaluated as successful those cases in which inserted implants were osseointegrated against the force of over 20 N at the secondary operation almost 6 months after insertion.
4. Statistical analysis

The Mann-Whitney U-test was used to compare between the PCBM reconstruction group and the native bone group, and the Wilcoxon T-test to compare between the CT value of cancellous bone only in the same group and that including compact bone. Also, we used χ² examination in the osseointegrated rate of the inserted implants. In all cases, p < 0.05% was considered to indicate a significant difference.

Results

1. Postoperative infection and gingival condition (Table 3)

Postoperative infection was not seen in any case. Even in case 6 no infection occurred in spite of exposure of the tray after surgery by intra-oral approach. Vestibuloplasty was not necessary in cases 1, 3, or 5 because the gingiva had already become attached, while vestibuloplasty was necessary to attain the attached gingiva on removing the tray in cases 2 and 4, and at the secondary operation in case 2. The perioseal retention technique was performed in all cases. Gingival or mucosal graft was not performed.

2. Macroscopic observation of bone formation (Table 3)

In all cases, new bone was formed in the PCBM filled area, of which the hardness was equal to that of the native bone (Fig. 2c).

3. Observation of bone formation by panoramic tomography (Table 3)

In all cases, bone opacity was close to that of the native bone, but still lower in 3 cases (Fig. 2e).

4. Examination by CT

a) Morphological analysis (Fig. 4)

The compact bone was clearly differentiated from the cancellous bone in the native bone group,
whereas in the PCBM reconstruction group the compact bone was thin as a whole, and in some cases was not clearly differentiated from the cancellous bone.

b) CT value measurement

The CT value of the PCBM reconstruction group was 671.8 HU maximum, 90.6 HU minimum, 297.1 HU on average (SD: 99.4 HU) for the cancellous bone, and 668.7 HU maximum, 192.1 HU minimum, 381.3 HU on average (SD: 119.7 HU) when the compact bone was included. On the other hand, the CT value of the native bone group was 1105.3 HU maximum, 131.1 HU minimum, 528.9 HU on average (SD: 140.1 HU) for the cancellous bone, and 1205.1 HU maximum, 147.4 HU minimum, 629.1 HU on average (SD: 172.8 HU) including the compact bone. In the PCBM reconstruction group, no significant difference was seen in CT value whether the compact bone was included or not, whereas in the native bone group, the CT value was higher with $p < 0.05$ in the area including the compact bone. Comparing the PCBM reconstruction group and the native bone group, whether the compact bone was included or not the CT value was significantly higher in the native bone (Table 4). According to the Misch criteria, in

### Table 3  Clinical evaluation after reconstruction

<table>
<thead>
<tr>
<th>Case</th>
<th>Attached gingiva</th>
<th>Postoperative infection</th>
<th>Condition of bone formation</th>
<th>Achievement of osseointegration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Macroscopic</td>
<td>Panorama X-ray</td>
</tr>
<tr>
<td>1</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
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<td>4</td>
<td>-</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>5</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

(1) In all cases, bone formation was seen visually and on palpation, and the hardness was equal to that of native bone (+).
(2) Bone opacity was close to that of the native bone but still lower on panoramic tomography (+) in three cases, while it was equal or nearly equal (+ +) in the remaining three cases.
(3) Compact bone thickness was evaluated on bucco-lingual view CT images. The bone on the PCBM reconstruction side was thinner than the native bone on the opposite side in all cases.
(4) Osseointegration 6 months after implant insertion was evaluated. (number of cases with osseointegration/number of inserted implants)

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**Fig. 4**  CT images: We observed the compact and cancellous bone structures of implanted parts on bucco-lingual and axial view images. The compact bone of the PCBM reconstructed side (B) was clearly thinner than that of the native bone on the opposite side in the same case (A).
Table 4  CT values of the cancellous bone

<table>
<thead>
<tr>
<th></th>
<th>Cancellous bone (HU)</th>
<th>Compact + cancellous bone (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native bone</td>
<td>528.9 ± 140.1</td>
<td>629.1 ± 172.8 (*)</td>
</tr>
<tr>
<td>PCB BM</td>
<td>297.1 ± 99.4</td>
<td>381.3 ± 119.7 n.s.</td>
</tr>
</tbody>
</table>

* : P < 0.05

CT values were significantly higher in the native bone group than in the PCB BM reconstruction group, whether the compact bone was included or not.

Table 5  Evaluation of the bone quality by Misch classification

<table>
<thead>
<tr>
<th>Misch classification</th>
<th>Native bone</th>
<th>PCB BM reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>D2</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>D3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total areas</td>
<td>17</td>
<td>13</td>
</tr>
</tbody>
</table>

CT values of all implant inserted areas were classified according to the Misch classification. Almost all native bone areas (total 17 areas) were grade 2 or 3, while all areas in the PCB BM reconstruction group (total 13 areas) were grade 3 or 4.

Fig. 5  Reconstructed length and CT value: The CT value of the over-3 cm-length cases was significantly (p < 0.05) lower than that of the native bone, but no significant difference was seen in the under-3 cm-length cases.

Contrast to the native bone group, most of which were grade 2 or 3, all cases in the PCB BM reconstruction group were grade 3 or 4 (Table 5). In 5 cases with grade 4, little difference was seen in the average CT value between the area including the compact bone (296.6 HU) and the area of the cancellous bone alone (291.7 HU).

c) Reconstructed length and CT value

The average CT value of the cancellous bone in the reconstructed cases of under-3 cm-length was 546.3 HU (SD: 134.0 HU), and that of the cases of over-3 cm-length was 259.7 HU (SD: 94.4 HU). When the compact bone was included, the average CT value was 545.4 HU (SD: 116.4 HU) in the under-3 cm-length cases, and 360.2 HU (SD: 124.9 HU) in the over-3 cm-length cases, all of which were lower. Comparing the PCB BM reconstruction group and the native bone group, the CT value of the over-3 cm-length cases was significantly (p < 0.05) lower than that of the native bone, but no significant difference was seen in the under-3 cm-length cases (Fig. 5).
5. Osseointegrated rate of the inserted implants

In cases 1 to 5 application was done with fixed-type final restoration without denture, but in case 6 a denture-type was used due to financial limitations (Fig. 2d, 2e). Evaluating the osseointegrated rate of inserted implants at re-entry, there was no significant difference, with 13 among 13 (100%) in the PCBM reconstruction group, and 16 among 17 (94.1%) in the native bone group.

Discussion

1. Evaluation of reconstructed bone quality

Long-term bone resorption and bone fracture have been reported as postoperative complications of mandibular reconstruction. However, only finite-element models for analyzing bone strength have been reported, and no clinical case has been reported yet. Most studies of bone resorption have been measurements of bone height with standardized X-ray images, and few have been bone structural analysis. According to our study, although macroscopic observation shows new bone of good quality in all PCBM reconstructed cases, orthopantomography shows that the bone opacity in half of cases was lower than that of native bone even one year after surgery. Marx et al. report the same, but not all reports refer to the bone quality. In our study, case 2, which had the lowest CT value of all cases, showed the same opacity as the surrounding bone on orthopantomography. Therefore, orthopantomography is effective in measuring alveolar bone height, but it is not reliable for the X-ray lucent evaluation of bone formation, for which further detailed examinations like CT are essential.

There have been many animal studies and clinical reports concerning the bone quality after bone graft or distraction osteogenesis. However, most of these analyze small areas related with implants, which are expected to obtain bone conduction from surrounding bone. On the contrary, because this cannot be expected with reconstructed bone over large areas, the results of these studies are not always helpful for the analysis of bone quality after PCBM reconstruction. In this study we evaluated each reconstructed compact and cancellous bone morphologically on CT images as well as quantitatively on the basis of CT images.

2. Evaluation method for compact bone

Miyamoto et al. reported that not the cancellous bone volume but the cortical bone thickness was the factor which most influenced implant stability at the time of surgery, measuring only cortical bone thickness on CT. They scanned CT images at a slice thickness of 1.0 mm, and reported that the mandibular cortical bone was 2.2 mm and the maxillary cortical bone was 1.4 mm on average. However, observation at a thinner slice thickness, such as in histological examination, examination by PQCT and micro CT is necessary, as the cortical bone of the PCBM reconstruction group is thinner than that of the native bone group.

3. Evaluation method for cancellous bone

Munakata et al. reported that the CT value of the cancellous bone was higher at the edentulous part than at the dentulous part, while Chiba observed that the extraction wound became more compact with callus made immediately after the extraction, and that the following remodeling change made the crestal bone around the wound more compact, but the inner bone of the wound more coarse.

In this study, the PCBM reconstruction group showed significantly lower CT value than the native bone group even in the same edentulous area. Fukutomi and Shapurian mentioned that the CT value of mandibular cancellous bone was lower at the molar part than at the anterior teeth part. The value of the PCBM reconstruction group in this study was 381.3 HU ± 119.7 HU including compact bone, and 297.1 HU ± 99.4 HU at cancellous bone alone, which was the same value as that of the molar part of the native bone. When the CT value is low, bone strength is a concern, but clinically neither torsion nor loose screws were seen on removing the tray.

4. Relation with implant insertion

The Misch classification, which is commonly used to evaluate implant inserted bone, allows evaluation of the CT value of both compact and cancel-
lous bone at the location of the inserted implant. However, there is no consensus on what part should be measured in order to evaluate the bone quality by CT value for implant insertion, for example Fukutomi limited the measurement to the cancellous bone, and Shapurian measured the outer compact bone. Munakata et al. noted this problem, and measured the CT value of both the compact and cancellous bone. In this study, we measured the CT value of both compact and cancellous bone as well as cancellous bone alone, and the CT value of the PCBM reconstruction group was significantly lower than the average of the native bone group. Shapurian and Lee argued that the bone quality classified as D4 by Misch was most fragile, and the success rate of inserted implants was also lowest, which means that the Misch classification is rational when limited to the success rate of implant insertion. In this study, the compact bone of the native bone group was classified as D2 to D3, except in one case, while that of the PCBM reconstruction group was classified as D3 to D4, which is thin and fragile. We could not assess the difference of D4 between the PCBM reconstruction group and the native bone group as the number of controls was small and no D4 case was found. The osseointegrated rate of implant insertion of present study was equal to that of the native bone, because we coped with fragile bone by using the two-time method of implant insertion, setting a 6-month latency period, and so forth.

5. Differences according to the length of reconstruction

As a result of our study, although the CT value of the PCBM reconstruction group was lower than that of the native bone in cases in which the resected range was short, no statistically significant difference was seen. However, the longer the reconstructed range, the lower the CT value. Comparing the CT value at 5 parts in case 5, in which the reconstructed range was long, the central part had the lowest CT value. In this reconstruction method, new bone is made firstly from bone marrow cells, with additional bone conduction from remaining bone as well as bone formation from the periosteum. When the reconstructed range is long, since the central part tends to be distant from surrounding bone formation and is insufficient in blood supply, there is a concern that there is little newly formed bone and that both the CT value and bone strength are low.

In conclusion, although implant insertion was possible in the PCBM reconstructed bone, it had thinner cortical bone and showed lower CT values compared with the native bone. The longer the reconstructed range, the stronger this tendency. However, since the bone strength is affected greatly not only by bone minerals but also by bone structures, further investigation of bone microstructures is necessary.

References


