Introduction: Pediatric digital amputations are rare compared to adult cases. Although the indications for digital replantation in children are generally more liberal and aggressive, they become rather ambiguous when fingertips are involved, especially those of the fingertip at the level of mid nail bed (middle-type). Previously, we reported that exploration in pediatric (6-year-old and younger) middle-type fingertip amputation found suitable vessels for replantation in 50% of times but the result of subsequent replantation was always successful. Moreover, we experienced an overall success rate of 67% in exploration cases including those of subsequent replantation with suitable vessels and composite grafting without suitable vessels. This was higher than a success rate of 57% in cases treated with primary composite grafting without exploration. Recently, we have encountered four additional cases of pediatric middle-type fingertip amputation. Therefore, we reviewed and re-analyzed all our cases to verify the value of exploring suitable vessels for digital replantation over primary composite grafting, especially in early childhood, as a follow-up to our previous report.

Method: A retrospective review of cases involving the surgical treatment of young children (6 years or younger), with single-digit complete middle-type fingertip amputations from 1993 to 2016 was conducted. Cases were divided into two groups: cases underwent reattachment as composite graft primarily and cases underwent exploration for suitable vessels for replantation. In the latter group when suitable vessels for replantation were found, replantation was attempted. On the other hand, when no suitable vessels were found, amputated parts were treated as secondary composite graft with or without pocket method.

The success of replantation or reattachment as a composite graft was judged on the basis of the clinical records.

Results: A total of 17 consecutive cases were identified, including 13 cases that were previously reported and four new cases. Of the four new cases, replantation was successful in three cases, while simple composite grafting failed after exploration in the other case. The probability to find suitable vessels increased to 60% with the addition of three successful replantations. However, the overall success rate for vessel exploration (70%) did not show statistical significance compared to that of primary composite grafting (57%).

Conclusion: We, again recommend exploration for amputations at this level with a view to replantation. Where microsurgical replantation is not possible, the use of the pocket technique can lead to a higher chance of graft survival.

Keywords: Distal fingertip amputation; early childhood; exploration; replantation; composite graft
children, with variable, sometimes disappointing results [6, 7]. On the other hand, replantation of such amputations with microvascular anastomoses in children has been reported with apparently more successful results [8]. However, most of these reports included a wide range of age groups, ranging from infants to schoolchildren, in addition to a heterogeneous mix of hand sizes and amputation levels [4, 5, 9–12]. Previously, we have reported our findings in the article ‘validity of exploration for suitable vessels for replantation in the distal fingertip amputation in early childhood: Replantation or composite graft’ in 2013 [13]. In this report, we discussed whether exploration for suitable vessels for replantation or reattachment as a composite graft should be carried out for the middle-type fingertip amputation (amputation between the distal phalangeal tip and lunula), as the treatment choices remain rather ambiguous for this type of amputation [3, 6, 9, 11, 12, 14]. Our results encouraged exploration for suitable vessels for replantation in these middle-type amputations, because, on exploration, suitable vessels were found in 50% of times with 100% successful replantation in six cases, resulting in the overall success rate for the explored cases was 67%, whereas that for primary composite grafting cases was 57%.

After publishing our previous report, we experienced additional cases and modified our mode of treatment. Subsequently, our recommendation for exploration for the middle-type could be validated more, whereas, there are points which require reconsideration. This paper updates our latest results of the treatment for the distal fingertip amputation in early childhood focusing only on the middle-type as a follow-up to our previous report. This work has been reported in line with the PROCESS criteria [15].

**Methods**

The surgical techniques are the same as previously reported except the following two points: we upgraded the microscope to OPMI® PENTERO® 900 (Carl Zeiss Meditec AG, Jena Germany), which provides a brighter surgical field and a more powerful magnification. For the postoperative bloodletting, currently we use the chemical leech technique [13, 16]. A very small amount (0.1 to 0.2 ml) of diluted calcium heparin of 500 units per 0.1ml was injected into the amputated part using 27G needle. Depending on the color or degree of congestion of the replanted part, the heparin solution was injected either once or twice per day in order to maintain continuous small amount of bleeding from the fish-mouth skin excision wound.

After receiving approval from our institutional review board, we conducted a retrospective chart review of all cases involving the surgical treatment of young children (6 years or younger), who underwent single-digit complete fingertip amputations of the middle-type (amputation at the level of mid nail bed between the distal phalangeal tip and lunula) from 1993 to 2016 at Okinawa Prefectural Chubu Hospital; a community-based teaching hospital. The patient charts were reviewed and analyzed. We previously classified distal fingertip amputation into three types as follows: the distal-type was distal to distal phalangeal tip, the proximal type was proximal to the lunula, and the middle-type was in between the other two.

The level of injury was judged by the dorsal aspect of the amputated edge [13]. Cases previously reported were also included. Cases were divided into two groups: cases underwent reattachment as composite graft primarily (primary C.G. group) and cases underwent exploration for suitable vessels for replantation (exploration group). In the latter group when suitable vessels for replantation were found, replantation was attempted. On the other hand, when no suitable vessels were found, amputated parts were treated as secondary composite graft with or without pocket method based on the surgeon's preference.

The success of replantation or reattachment as a composite graft was judged on the basis of the clinical and photographic records, as we previously reported. Briefly, the operation was considered a “success” if more than half of the amputated part survived or showed a satisfactory appearance. It was considered a “failure” if less than half of the amputated part survived or if the fingertip had an unacceptable appearance. Then results of primary C.G. group and exploration group were compared using the Fisher’s exact test for statistical analysis.

**Results**

A total of 17 consecutive cases are included in this report, which consists of the previously reported 13 cases and four new cases with ages ranging from 1 year and 8 months to 6 years and 5 months (mean 3 years and 7 months). The body weight ranged from 10.2 to 19.5 kg (mean 15.1 kg). The mean follow up period was 131.6 days, ranging from 11 to 598 days. All amputations were caused by crush or avulsion injuries.

There were no additional cases that underwent primary reattachment as a composite graft after 2013. Therefore, as previously reported, primary reattachment as a composite graft was performed in seven cases with four successes (success rate: 57%). The mean age was 3 years and 2 months and the mean body weight was 14.7 kg. Distribution of the injured finger was one case of thumb, one case of index finger, and five cases of middle finger. The direction of the amputation plane was vertical which is perpendicular to the horizontal or palmar plane of the digit in four cases, proximally and distally oblique to the horizontal plane of the digit in two cases, and radio-ulnar oblique to the sagittal plane of the digit in one case.

Exploration for replantation was carried out in ten cases, including the recent four cases, with age ranging from 1 years and 8 months to 6 years and 2 months (mean 4 years). The body weight ranged from 10.2 to 19.5 kg (mean 15.8 kg). Suitable vessels for replantation were found in six cases.

The mean age of six cases with suitable vessels was 3 years and 6 months, ranging from 1 year and 8 months to 6 years and 2 months, and the mean body weight was 14.2 kg, ranging from 10.2 to 18.6 kg. Distribution of the injured finger was index finger in one case, middle finger in three cases, and ring finger in two cases. The direction of the amputation plane was vertical in three cases, proximally oblique in two cases, distally oblique in one case. Successful replantation was achieved in all six cases with suitable vessels (Figure 1). The level of arterial anastomosis was Ishikawa’s subzone 2 in three cases and subzone 3
in three other cases [17]. Venous anastomosis could not be achieved in any cases. Instead, both arteriovenous shunting and bloodletting with skin excision were performed in one case. Three recent cases underwent bloodletting with skin excision using chemical leech technique for the early days of their bloodletting periods. Of the remaining two cases, one had serial pin-prick to encourage venous bleeding while the other one did not. Operative time ranged from 125–233 minutes (mean 178.5 minutes). The total hospital stay was between 6 to 11 days (mean 8.7 days) (Table 1). No cases required transfusion.

In addition to the previously reported three cases, another case without suitable vessels for anastomosis underwent subsequent secondary reattachment of the amputated part as a composite graft without pocket method (Figure 2). The mean age of the four additional patients (secondary C.G. group) was 4 years and 8 months (range, 2 years and 10 months to 6 years and 5 months). The mean body weight was 18.3 kg (range, 13.6 to 24 kg). Distribution of the injured finger was middle finger in three and small finger in one case. The direction of the amputation plane was vertical in three cases and proximally oblique in one case. The level of vessel stump in the amputated part was Ishikawa’s subzone 2 in two cases and unknown in the other two cases. Including the recent case, simple reattachment as a composite graft failed in three cases. Still, there was only one successful composite graft in which the pocketing of the composite graft method was performed. Operative time including the exploration and subsequent reattachment as a composite graft ranged from 40–112 minutes (mean 79.8 minutes) (Table 2).

Analysis between the overall success rate of exploration for suitable vessels for replantation (70%) and that of primary composite grafting (57.1%) did not show statistical significance (Fisher, p = 0.48).

Discussion

After publishing our previous report in 2013, we encountered four more cases of the middle-type fingertip amputation. Combining the outcomes of all the cases, some of our previously reported results could be further validated while others should be reconsidered.

There are two issues that should be validated further based on this updated report.

The first issue is “how often suitable vessels for replantation are found”; we previously reported that suitable vessels could be found 50% of times. However, based on the current result, the probability has increased to 60%, with a persistently 100% success rate in the subsequent replantation. The improvement in success rate may have contributed partly by the use of a better microscope with higher magnification and brighter surgical field as well as the introduction of the chemical leech technique. The direction of amputation plane may have been a positive contribution for the preservation of suitable vessels, as the more proximal volar aspect of the fingertip is amputated,
Table 1: A list of cases with suitable vessels for replantation.

| Case  | Age           | Body weight (kg) | Injured digit | Direction of the amputation plane | Subzone | Days of bloodletting | Days for chemical leech | Use of systemic heparin | Use of aspirin | Use of low molecular dextran | Use of systemic Prostaglandin E1 | Result | Operation time (minutes) | Days in hospital |
|-------|---------------|------------------|---------------|----------------------------------|---------|----------------------|-------------------------|------------------------|----------------|----------------------------|----------------------------------|--------|--------------------------|------------------|
| 8     | 4 years 4 months | 16               | Middle        | Distally oblique                 | 3       | 0                    | N.A.                    | No                     | No            | Yes                        | No                               | Success | 202                      | 7                |
| 9     | 4 years 9 months | 18.2             | Ring          | Vertical                         | 2       | 0                    | N.A.                    | Yes                    | No            | No                        | No                               | Success | 125                      | 6                |
| 10    | 2 years 4 months | 11.5             | Ring          | Vertical                         | 3       | 5*                   | N.A.                    | Yes                    | Yes           | No                        | Yes                              | Success | 233                      | 11               |
| 11    | 6 years 2 months | 18.6             | Middle        | Vertical                         | 3       | 7                    | 1                       | Yes                    | Yes           | No                        | Yes                              | Success | 204                      | 10               |
| 12    | 1 year 8 months  | 10.2             | Index         | Proximally oblique               | 2       | 5                    | 4                       | Yes                    | Yes           | No                        | Yes                              | Success | 166                      | 9                |
| 13    | 1 year 8 months  | 10.8             | Middle        | Proximally oblique               | 2       | 3                    | 3                       | Yes                    | No            | No                        | No                               | Success | 141                      | 9                |
| Mean  | 3 years 6 months | 14.2             |               |                                  | 2.5     | 3.3                  | 2.7                     |                       |               |                           |                                  | 178.5 | 8.7                      |                  |

(* Both arteriovenous shunting and bloodletting with skin excision were performed; N.A.: not available.)
there is a higher chance to possess proximal stumps of the arteries. However, we could not show the difference in the direction of amputation plane as well as levels of subzone between cases with and without suitable vessels due to small number of cases (Table 3).

The second is the recommendation for some form of pocket method for cases without any suitable vessel as a backup for replantation attempts. The reason for amputation in all 17 cases was either a crush or an avulsion injury. This trend is very common in developed countries [18]. These types of amputation are unfavorable to graft take, because both the amputated part and amputated stump are severely damaged, compared to a guillotine amputation. The overall success rate of ten simple composite grafting, including the current case is only 40%. In order to expand the area of “graft take”, the introduction of additional blood circulation into the amputated part from the pocket site is still highly recommended especially when significant crush injury or protracted ischemia is suspected [13].

As a result, the success rate after exploration increased from 66.7% (as we previously reported) to 70.0% after incorporating the results from this report. However, it does not show statistically significant difference compared to that of the primary composite grafting (57%). Although the number of cases is small due to its rare incidence, this trend in finding suitable vessels is steadily increasing with persistent success in replantation.

On the other hand, another finding from our previous report needs to be reconsidered; regarding the subzone, we previously reported that cases with suitable vessels

Figure 2: Failed secondary simple reattachment as composite graft in case 17. An amputated part was attached as composite graft after exploration (above left, second to the left, second to the right, right). Finding four weeks after surgery showed necrosis of the attached amputated part (below left). Findings six months after surgery (below second to the left, center). Comparison between affected (yellow arrowhead) and healthy (white arrowhead) fingertips six months after surgery (below left).

Table 2: A list of cases without suitable vessels subsequently treated with secondary composite graft.

| Case | Age       | Body weight (kg) | Injured digit | Direction of the amputation plane | Subzone | Result  | Operation time (minutes) | Days in hospital |
|------|-----------|------------------|---------------|-----------------------------------|---------|---------|--------------------------|------------------|
| 14   | 4 years 9 months | 19.5             | Middle        | Proximally oblique                | 2       | Failure | 110                      | 7                |
| 15   | 6 years 5 months  | 24               | Middle        | Vertical                          | 2       | Success* | 112                      | 4                |
| 16   | 2 years 10 months | 13.6             | Small         | Vertical                          | N.A.    | Failure | 40                       | 5                |
| 17   | 5 years     | 16               | Middle        | Vertical                          | N.A.    | Failure | 57                       | 9                |
| Mean | 4 years 8 months | 18.3             |               |                                   | 2       |         | 79.8                     | 6.3              |

(* abdominal pocket method was used; N.A.: not available.)
for replantation had higher levels of Ishikawa’s subzone, with two cases of subzone 3 and one case of subzone 2. This trend has not been confirmed in the current result. Based on the results of six cases with suitable vessels for replantation, distribution of the level of subzone is the same for subzone 2 and subzone 3. As we mentioned above, we could not find the difference in the direction of amputation plane as well as levels of subzone between cases with and without suitable vessels (Table 3).

Conclusion
Our updated result showed exploration in the middle-type amputation in early childhood found suitable vessels for replantation in 60% of times but with 100% success rate of subsequent replantation. However, overall result of exploration still did not show statistical significance compared to the results of primary composite grafting due to inadequate number of cases as pediatric fingertip amputations are rare. In order to further validate our findings, additional cases are required.

Here, we again recommend exploration for the middle-type amputations with a view to replantation, irrespective of the mechanism of injury. When microsurgical replantation is not possible, the use of the pocket technique can lead to a higher chance of graft survival.

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Competing Interests
The authors have no competing interests to declare.

Table 3: Comparison of cases with and without suitable vessels for replantation.

|                      | Cases with suitable vessels for replantation (6 cases) | Cases without suitable vessels for replantation (4 cases) |
|----------------------|-------------------------------------------------------|--------------------------------------------------------|
| Mean age             | 3 years 6 months                                      | 4 years 8 months                                       |
| Mean body weight (Kg)| 14.2                                                   | 18.3                                                   |
| Subzone level        |                                                       |                                                         |
| Subzone 2            | 3                                                     | 2                                                      |
| Subzone 3            | 3                                                     | 0                                                      |
| Direction of the amputation plane |                                                      |                                                         |
| Vertical             | 3                                                     | 3                                                      |
| Proximally oblique   | 2                                                     | 1                                                      |
| Distally oblique     | 1                                                     | 0                                                      |
| Mean operation time (minutes) | 178.5                                                   | 79.8                                                   |
| Mean days in hospital| 8.7                                                    | 6.3                                                    |

Author Contribution
Imaizumi, Atsushi has substantial contributions to the conception and design of the work, acquisition, analysis, and interpretation of data for the work, the drafting the work, critical revision for important intellectual content, and provided final approval of the version to be published.

Kadota, Hideki has substantial contributions to conception and design of the work, acquisition, analysis, and interpretation of data for the work, and provided final approval of the version to be published.

Guarantor
Imaizumi, Atsushi is the guarantor.

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