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Comparative Analysis of Steel Plates and PLA Used for Joint Repair in Humans and Canines

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ABSTRACT

The exploration of fracture internal fixation materials has been one of the research hotspots in the field of biomedical materials. The traditional internal fixation material for fracture is metal fixation. Although its mechanical strength is very large, it can not be degraded and absorbed in human body after implantation of human body or canine joint, which requires a secondary operation to remove, which not only brings pain to patients, but also causes economic pay. Therefore, the development of a biodegradable fracture internal fixation material has become the goal of many researchers. Polylactic acid (PLA) is nontoxic and harmless, has good biocompatibility and strong mechanical properties. It can be degraded in vivo after implantation. The degradation products are CO₂ and H₂O. For the study of the feasibility of polylactic acid as a substitute for common fracture fixation materials, 18 northern Chinese pastoral dogs were randomly divided into blank group, PLA group and steel plate group. The data were recorded according to the Wakitani score from the first week to the fifteenth week after operation. First, all the indexes were divided into two categories by principal component analysis, then the blank group, steel plate group and PLA group were fitted and compared. Finally, it is concluded that PLA is more beneficial to joint repair than steel plate.

1. Introduction

Polylactic acid, as a substitute for metal fixation on bone repair, has a very broad market prospect. It can be degraded into CO₂ and H₂O in vivo, so that patients do not need to secondary surgery. It also reduces economic efforts. Up to now, however, domestic PLA are generally used in human joint repair, and dogs, such as search and rescue dogs, need to reduce the suffering of secondary removal of metal solids and reduce the cost of treatment. Therefore, the possibility of PLA application in canine joint repair should be considered.

As an important method to achieve bone defect repair, bone tissue engineering is a scaffold with good biocompatibility and specific three-dimensional structure. At the same time, the scaffold can be gradually degraded and

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completely replaced by new bone after implantation.\textsuperscript{[3]} at present, metal solids are usually used as scaffolds to help joint repair. However, metal solids are not compatible with human body in joint repair and need secondary surgery to remove them. In contrast, polylactic acid degrades in the body as the patient’s injury improves, thus alleviating the patient’s pain.

In this experiment, the evaluation of cartilage defect area repair tissue in each group of experimental animals combined with histological staining was performed with Wakitani cartilage repair score\textsuperscript{[4]} histological score, double blind, and two orthopaedic physicians familiar with cartilage repair histology evaluation. Cell morphology, matrix staining, surface regularity, cartilage thickness, binding of repair tissue to surrounding cartilage and Col-II protein content were used as the evaluation basis to evaluate the experimental bodies in each group. Compared with the steel plate, the PLA can not only degrade in vivo, but also be better than the steel plate in joint repair. Therefore, PLA as a fixation material for canine joint fixation can not only reduce the cost and enhance the effect, which is also instructive for PLA joint repair for some other organisms.

2. Principal Component Analysis based on All Evaluation Indicators

2.1 Determination of parameters after principal component analysis

Because of too many original indexes, the difficulty and complexity of the analysis problem are increased, and in this experiment, there is a certain correlation between multiple variables. Accordingly, the six selected indexes, cell morphology, matrix staining, surface regularity, cartilage thickness, binding of repair tissue to peripheral cartilage and Col-II protein content were reduced.

There are 6 samples and 6 indexes, which can form a sample matrix $X$ of $n \times p$ size:

$$
X = \begin{bmatrix}
X_{11} & X_{12} & \ldots & X_{16} \\
X_{21} & X_{22} & \ldots & X_{26} \\
\vdots & \vdots & \ddots & \vdots \\
X_{61} & X_{62} & \ldots & X_{66}
\end{bmatrix} = (X_1, X_2, \ldots, X_6)
$$

(1)

It is standardized to calculate the mean value by column:

$$
\bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i
$$

(2)

and standard deviation:

$$
S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2}
$$

(3)

Calculated standardized data $X_{ij}$, the original sample matrix was standardized to:

$$
X = \begin{bmatrix}
X_{11} & X_{12} & \ldots & X_{16} \\
X_{21} & X_{22} & \ldots & X_{26} \\
\vdots & \vdots & \ddots & \vdots \\
X_{61} & X_{62} & \ldots & X_{66}
\end{bmatrix} = (X_1, X_2, \ldots, X_6)
$$

(4)

Then the co-variance matrix of the standardized sample is calculated:

$$
R = \begin{bmatrix}
r_{11} & r_{12} & \ldots & r_{16} \\
r_{21} & r_{22} & \ldots & r_{26} \\
\vdots & \vdots & \ddots & \vdots \\
r_{61} & r_{62} & \ldots & r_{66}
\end{bmatrix}
$$

(5)

inside:

$$
t_{ij} = \frac{1}{n-1} \sum_{k=1}^{n} (X_{ki} - \bar{X}_k)(X_{kj} - \bar{X}_j) = \frac{1}{n-1} \sum_{k=1}^{n} X_{ki}X_{kj}
$$

(6)

Then the eigenvalues and Eigenvectors of the R are calculated, in which the blank group, the steel plate group and the PLA group obtain the Eigenvectors respectively:

| Blank group: | 0.0001 | 0.0012 | 0.0022 | 0.0076 | 0.0175 | 5.9715 |
| Steel plate group: | 0.0003 | 0.0006 | 0.0026 | 0.0240 | 0.0515 | 5.9210 |
| Group PLA: | 0.0002 | 0.0012 | 0.0045 | 0.0100 | 0.0512 | 5.9329 |

Then calculate the contribution rate:

The contribution rate $= \frac{\lambda_i}{\sum_{i=1}^{6} \lambda_i}$

(7)

Finally, the contribution rate of principal components of blank group, steel plate group and PLA group was obtained:

| Blank group: | 0.0000 | 0.0002 | 0.0004 | 0.0013 | 0.029 | 0.9692 |
| Steel plate group: | 0.0000 | 0.0001 | 0.0004 | 0.0040 | 0.086 | 0.9094 |
| PLA group: | 0.0000 | 0.0002 | 0.0008 | 0.0017 | 0.085 | 0.9124 |

In order to ensure that the final data has more than 95% integrity, the latter two principal component indexes are taken, so that the data loss rate is kept below 5%. Finally, the winner’s composition coefficient is shown in Table 1:
2.2 Interpretation of the Principal Component Parameters and the Finding of the Principal Component Indexes

As can be seen from Table 1, all the indexes of blank group, steel plate group and PLA group have similar positive loads in principal component 1, and the proportion of item 1 and item 6 is higher. Therefore, principal component 1 can be interpreted as the recovery of surrounding tissues.

As can be seen from Table 2, the second principal component has different types of indexes compared with the three groups of experiments, but the main comparison of the steel plate group and the PLA group of principal component 2, the fourth and the fifth index occupy a high proportion. Therefore, principal component 2 can be interpreted as recovery of damaged matrix and cartilage.

Finally, the principal components of the blank group and the PLA group are shown in Table 2:

### Table 1. Principal Component Coefficient

| Component 1 | Component 2 | Component 1 | Component 2 | Component 1 | Component 2 |
|-------------|-------------|-------------|-------------|-------------|-------------|
| blank group | Steel plate group | PLA group |
| 0.4089      | 0.064       | 0.095       | 0.3080      | 0.0214      | 0.4097      |
| 0.3078      | 0.0306      | 0.031       | 0.3078      |             |             |
| 0.3079      | -0.0261     | 0.095       |             | -0.1814     |             |
| 0.4082      | 0.0490      | -0.1814     |             |             |             |

### Table 2. Principal Component Score

| Component 1 | Component 2 | Component 1 | Component 2 | Component 1 | Component 2 |
|-------------|-------------|-------------|-------------|-------------|-------------|
| blank group | Steel plate group | PLA group |
| 2.453       | -1.284      | 2.462       | 0.240       | 2.462       | 0.240       |
| 3.837       | -1.498      | 5.021       | -0.898      | 4.657       | -0.678      |
| 5.330       | -1.787      | 7.071       | -1.603      | 6.732       | -1.368      |
| 6.913       | -2.245      | 8.958       | -1.684      | 8.650       | -1.440      |
| 8.376       | -2.353      | 10.611      | -1.288      | 10.326      | -1.024      |
| 9.640       | -3.187      | 11.904      | -1.407      | 11.632      | -1.133      |
| 10.874      | -3.672      | 13.237      | -1.215      | 13.081      | -1.134      |
| 11.875      | -4.061      | 14.407      | -1.092      | 14.277      | -1.015      |
| 12.723      | -4.319      | 15.268      | -0.853      | 15.202      | -0.850      |
| 13.528      | -4.605      | 16.006      | -0.499      | 15.955      | -0.548      |
| 14.286      | -4.924      | 16.599      | -0.336      | 16.826      | -0.269      |
| 14.829      | -5.172      | 17.020      | -0.086      | 17.481      | 0.020       |
| 15.228      | -5.193      | 17.472      | -0.090      | 17.987      | -0.010      |
| 15.515      | -5.251      | 17.740      | 0.017       | 18.284      | 0.079       |
| 15.761      | -5.258      | 17.935      | -0.006      | 18.478      | 0.052       |

3. Fitting Curve Analysis of Experimental Indexes based on Principal Component Analysis

3.1 Curve Fitting Analysis of Principal Component 1

Using the sum of sine [3] in the Matlab to fit the three groups of data, the blank group fitting results are shown in Figure 1:

![Figure 1. Fitting results of blank group](image)

Fitting function:

\[ f(x) = a_1 \sin(b_1 \cdot x + c_1) \]  \hspace{1cm} (8)

Inside \( a_1 = 15.64, \ b_1 = 0.1004, \ c_1 = 0.05465 \)

The sum of square error is 0.1072, the goodness of fit is 0.9996, and the mean square error is 0.0945. Because the sum of square errors is SSE less than 1, the fitting effect is better.

The fitting results of the steel plate group are shown in Figure 2:
Figure 2. Fitting results of steel plate group

The fitting function is:

\[ f(x) = a_2 \cdot \sin(b_2 \cdot x + c_2) \]  \hspace{1cm} (9)

Inside \( a_2 = 17.68 \), \( b_2 = 0.1096 \), \( c_2 = 0.06934 \)

The sum of square error is 1.339, the goodness of fit is 0.9961, and the mean square error is 0.334. Because the sum of error square SSE=1.339 is small, the fitting effect is better.

PLA group of fitting results are shown in Figure 3:

Figure 3. PLA group fitting results

The fitting function is:

\[ f(x) = a_3 \cdot \sin(b_3 \cdot x + c_3) \]  \hspace{1cm} (10)

Inside \( a_3 = 18.25 \), \( b_3 = 0.1047 \), \( c_3 = 0.05545 \)

The sum of square error is 0.7661, the goodness of fit is 0.998, and the mean square error is 0.2527. Because the sum of square error SSE=0.7661 is small, the fitting effect is better.

The fitting results show that the \( a_3 \) is greater than that of \( a_2 \). Therefore, in the same time, the upper limit of the recovery of the surrounding tissue of the PLA group is better than that of the steel plate group, because the \( b_2 \) is 0.1096 and the \( b_3 \) is 0.1047. As a result, the fitting function analysis of principal component 1 shows that steel plate can be replaced by PLA in the recovery of tissue around joint damage.

3.2 Curve Fitting Analysis of Principal Component 2

Using the smooth spline fitting (Smoothing spline) in the Matlab, the fitting results of the three groups of data are as follows:

4. Cluster Analysis of Experimental Indicators Based on Principal Component Analysis

4.1 Hierarchical Cluster Analysis

Clustering analysis is to classify the studied objects according to the characteristics of things themselves, so that the individuals in the same class have greater similarity and the individuals in different classes have greater differences. Is to classify subjects without prior knowl-
edge of classes \[^8\].

The distance between six experimental samples is calculated first \(dij, D=(dij)\), and the distance matrix between samples is obtained by using Euclidean distance \[^9\] as distance measurement method.

\[
d(\bar{x}_1, \bar{x}_2) = \sum_{k=1}^{n} |x_{1k} - x_{2k}|
\]

(11)

Take each sample as a class and \(G_1, G_2, G_3, G_4, G_5, G_6\), get the minimum distance of two or two of the six samples, and gather them into a class as \(G_7\). Compute the distance between the new class and the rest, and get the new distance matrix \(D_2\).

\[
D(G_2, G_1) = \min \{D(G_1, G_2), D(G_1, G_3)\}
D(G_6, G_1) = \min \{D(G_1, G_6), D(G_1, G_5)\}
D(G_6, G_7) = \min \{D(G_7, G_6), D(G_7, G_5)\}
D(G_6, G_7) = \min \{D(G_7, G_6), D(G_7, G_5)\}
\]

(12)

Find out the minimum of two distances in five samples, gather them into a class, and record them as \(G_8\). Compute the distance between the new class and the rest, and get the new distance matrix \(D_2\). By analogy, all experimental group samples are finally grouped into three categories.

4.2 Clustering Results and Category Determination

The experimental data of blank group, steel plate group and PLA group were systematically clustered to obtain the PLA spectral system diagram of steel plate group \[^10\] as shown in Figure 6 and Figure 7:

4.3 Analysis of Cluster Effect Maps

Analysis of cluster effect maps:
The damage period of the steel plate group was shorter than that of the PLA group, and the repair period was slightly longer than that of the PLA group. The results showed that the effect of PLA on joint repair was slightly slower than that of steel plate in week 4 to week 7. Moreover, the distribution of sample points in the 6th to 8th weeks of the plate genealogy rapidly compared with the PLA group, which indicated that the plate group had faster effect on joint repair than the PLA group in the 6th to 8th weeks, and the sample point distribution of the steel plate in the 9th to 12th weeks of the PLA; pedigree was more dense than that in the PLA group. This is the same conclusion as the previous section by fitting.

5. Conclusions

In this paper, the principal component analysis method is used to evaluate the joint repair, which simplifies the problem under the condition of minimizing the data loss rate. At the same time, two fitting methods and systematic clustering method are used to analyze the blank group. Effects of plate group and PLA group on canine bone repair. The results showed that PLA, like metal solids, had a significant effect on the repair of damaged joints compared with the blank group, and compared with the steel plate, the PLA had a slightly smaller effect on the early repair of canine joints than the steel plate. But the repair effect of PLA is stronger than that of steel plate. According to this result PLA the repair effect of the joint tends to converge earlier than that of the metal solid, and the patient recovers early and reduces the pain.

While the current PLA is mainly used for the repair of human joints, the analysis of experimental data shows that PLA can also replace metal solids such as steel plates for canine joint repair, and its effect as fracture fixation is better than that of metal solids. This provides a guiding idea for the study of whether PLA can be used as fracture fixation for joint repair in other organisms.

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