Feasibility of magnetic activation of a maxillofacial distraction osteogenesis, design of a new device

J. Boisson, N. Kadlub, H. Strozyk, P. Diner, A. Picard

Summary: In this paper, we report a study on the feasibility of a rodless magnetic activation of the mandibular distraction osteogenesis. The method is based on the torque applied between two unaligned permanent magnet. This torque depends on the size of the magnets, their shape, their composition, and the distance between them. In a geometric configuration close to the one we will face in a real distraction osteogenesis (namely in term of distance between the two magnets), we performed analytical study and confront the results to experiments. We observed a good agreement, and the transmitted force value is compatible to the force involved in a mandibular distraction REF. Then, we propose a design of a new distracting device with a cylindrical permanent magnet fixed to the threaded drive shaft with a magnetization orthogonal to the main axis. The activation of the distraction motion is realized thanks to a cylindrical magnet with its magnetization orthogonal to its main axis.

Introduction:

Distraction osteogenesis (DOG) has become an important part for the craniofacial surgeon’s armatorum [1]. With this technique, de novo bone lengthening occurs gradually. It is an essential procedure in children with craniofacial deformities, and is applied in a large board of malformation and localization (lower/upper face; congenital/acquired deformities) [2, 3].

Distraction osteogenesis involved an initial injury, then the recruitment of mesenchymal stem cells, mechanical linear force and callus consolidation. Indeed, a surgical osteotomy, followed by a latency period, then activation and finally consolidation [4].

First report of craniofacial DOG had been report by Snyder in 1973 [5], but we have to wait until 1992 to applied craniofacial DOG on children with congenital mandibular anomalies. Initially, McCarthy developed extra-oral distraction devices [6]. Extra-oral distraction devices were fixed to the bone through the bone by transcutaneous pins [2]. However, the psychological problems and the facial scarring led to the emergence of intraoral device. First intraoral distractor consisted in miniaturization of the extra oral devices [2], and then though the impulsions of Diner, craniofacial bone distraction device based on clinical and anatomical indication [7, 8]. Since McCarthy’s description DOG devices tend to be miniaturized and with better comfort for patient (removal activator, transmucosal activator…). However, despite this improving, craniofacial DOG need to be done through a transmucosal or transcutaneous activator, leading to several problems, as bacterial infectious entry, activator rod discomfort (rod keeps from dental occlusion), screw-tool fears, chronic wound, rod covered-up...[9,10].

State of Art

The limitations of the current techniques motivated many researchers to develop a 3rd generation of DOG devices.

For instance, two groups of distractor exist or are in development:

- Continuous automatic distraction [11]
- Discontinuous activated distraction.

In the past few years, various mechanisms had been proposed to achieve automated distraction,

- Electric motors. None of the internal distractors with electric motor was able to achieve a 1mm/days distraction; moreover motors raise the problems of biocompatibility [11, 12].
- Shape memory alloy or spring- assisted devices. These techniques raise the problem of the specific elasticity and force of each individual [11, 12].
- Hydraulic. Hydraulic system was found to be inconsistent and daily distraction distance decreased with times [11, 12].

In all this devices, distraction progress could not be measured without radiographic imaging [11, 12].

The other way, to improve DOG device is to achieve distraction through a distant activation.

Previously, Soubeiran (WO-A-0178614) [13] described a DOG device activated through a magnetic field. His device consisted in a centromedullar distractor, with an external magnet. Rotation of the distractor is performed by rotation of another magnet around the distractor device. This technique is not applicable in maxillofacial surgery, for many reasons: impossibility to use a centromedullar device, impossibility to turn around craniofacial bone, liability of the magnetic field applied and risk of materials and screws displacement.

Recently, our team developed a physical model of DOG device activated by a magnetic field, which is subject to a brevet deposit.

Material and methods

Physical Basis

First, we detail the basics of the physical model describing the interaction between two magnets. A permanent magnet is composed by a material which keeps an intrinsic magnetization $\vec{M}$after having been submitted to an external magnetic excitation. Therefore, it produces a static magnetic field $\vec{B}$ that can attract or repels other magnets. The magnetic field geometry depends on the magnet shape and on the position of the north and south poles. As a first approximation, whatever its form, we can model a magnet by a magnetic dipole $\vec{m} = \vec{M}V$ (with V the magnet volume), oriented in the same direction, and generated a dipolar magnetic field:

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi}\left(\frac{3\vec{r}(\vec{m}.\vec{r})}{r^5} - \frac{\vec{m}}{r^3}\right)$$

where μ_0 is the permeability of free space, and $\vec{r}$ the vector designing the position where we consider the magnetic field in respect of the position of the magnetic dipole. The form of Eq. (1) further we are from the magnet, lower the magnetic field is. The force is the mass times the acceleration, which corresponds to the sum of influences that changes the velocity of an object. In the International System of Units this is measure in Newton (N), this corresponds to a force when applied to a $1\ kilogram$ gives an acceleration of $1\ meter\ per\ second$ or approximatively to the weight induce by a mass of $0.1\ kg$. The torque is a vector that measures the tendency of a force to rotate an object about some axis. As it depends on the distance between the point of application of the force and the rotation axis, it is measured in $Newton\ meters$. In the case of two magnets c_1 and c_2 in interaction, the torque applied from c_2 on c_1 is $\vec{\Gamma} = \vec{m}_1 \times \vec{B}_2$.

Due to the difficulty summarized above of performing magnetic distraction with internal and external magnets align along their magnetization axes; we focused on a new geometry of activation based on the torque created between two magnets with a magnetization perpendicular to the axes going through their centers (see Fig. 1).

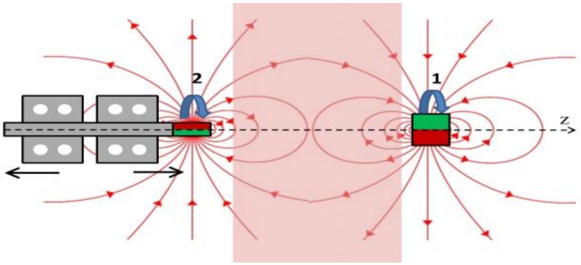

Figure 1: Device principle. Here the rotation of the external magnet applies a torque to the internal one inducing the distraction.

Indeed, when the magnet (1) rotates around the z-axis, the change in the magnetic field induces a torque (Γ) on the magnet (2) of the form: : $\Gamma \propto (m_1 m_2)/r^3 \ \sin\alpha$, where m_1 and m_2 are the magnetic dipole moment equivalent of magnet 1 and 2, r is the distance between the centers of the two magnets, and α the angle between their magnetizations($\alpha=0$ when they are collinear).

To simplify the problem, we only conducted 2D calculations and experiments on a reduced system of two magnets. We consider cylindrical magnets with dimension compatible with the distraction ($h_1=d_1=5$ mm and $h_2=d_2=30$ mm, see Fig. 2).

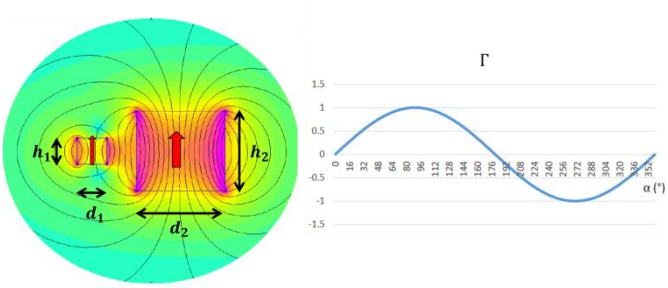

Figure 2: On the left, the streamlines of the magnetic field generated by the two cylindrical magnets. On the right, the evolution with the angle α of the torque applied on the internal magnet by the external magnet at an arbitrary distance r.

The calculation confirms the torque dependence with the angle α. It has to be noted that the torque is maximum for $\alpha=\pm 90°$.

The experiments took over the same geometry magnets defined above however for clamping issue we performed torque measurements on a bigger internal magnet ($h_1=d_1=10$ mm).

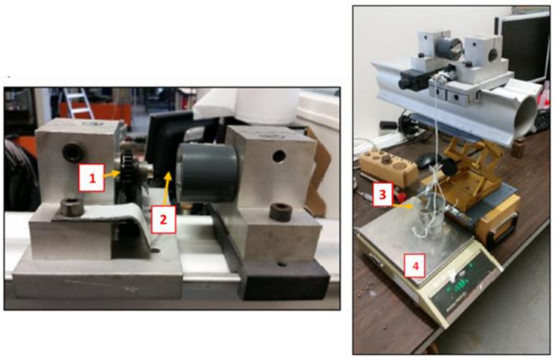

Figure 3: Picture of the torque measurement experimental set up. 1 is the internal magnet, 2 the external magnet, 3 the counterweight and force the precision scales.

The device was designed and realized in the Institute of Mechanical science and Industrial Applications of ENSTA-ParisTech. The results are reported in Fig. 4.

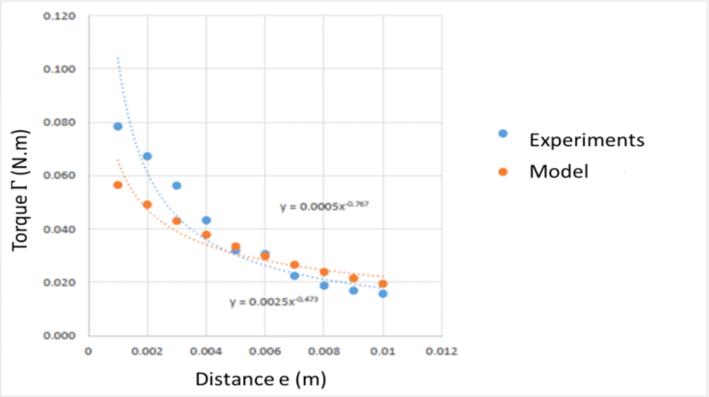

Figure 4 Results of the torque measurement.

Results

Discussion

Conclusions

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