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Research Article

Magnetically Controlled Spinal Implants: Current Trends, Future Perspectives, and Challenges

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Abstract – Spinal disorders are health problems that are frequently seen especially in individuals in the growing age and significantly affect the quality of life. Especially in parallel with the growth in childhood and adolescence, the fixed implants placed in the vertebrae are incompatible with the body characteristics. This causes the implant to remain small or fail and often requires additional surgical interventions. These second surgeries to replace or lengthen the implant are both painful and challenging for the patient. In this paper, magnetically controlled implants used in the treatment of slipped discs, spinal deformities, and similar spinal disorders are examined in detail. These systems, which are controlled by magnetic waves, have the potential to eliminate the incompatibilities that may occur by adapting to the growth and structural changes in the body with non-invasive methods. The adaptation of this system to the physiological development and growth of the patient reduces the need for surgical interventions and surgical compartments, shortens the general recovery time of the patients and provides a significant reduction in operation costs and provides economic contributions to the health system and the patient. The main aim of this study is to evaluate the current status and advantages of existing magnetically controlled implant technologies and to analyse their place in clinical use. In addition, to examine the challenges and problems encountered in these technologies and to investigate where this technology will evolve in the future. This paper aims to be a guiding resource both in current clinical practice and in future research and development studies.

Keywords – Magnetic Field, Spinal Deformity, Spine İmplant, Remote Control, Non-İnvasive Lengthening.

I. INTRODUCTION

In addition to being one of the supporting structures of our body, the spine contains the spinal cord, which has vital functions and plays a role in providing neural transmission. Although spinal injuries can be seen in all age groups, traumas and accidents in childhood are the most common causes of these injuries. Traumatic events such as falls, sports accidents and traffic accidents that may cause spinal damage in children can lead to serious problems such as nerve compression, slipped disc and even paralysis. In addition, congenital spinal anomalies may also increase the risk of injury and negatively affect spinal health [1]. Conventional implants used in the treatment of spinal injuries in children require additional surgical interventions such as replacement or lengthening of implants when the patient's growth potential is not taken into account. Since the current traditional surgical methods cannot provide solutions suitable for the

developing spine structure of the pediatric patient, there is a need to develop more effective and long-term solutions. Therefore, it is of great importance that the implants used in paediatric patients adapt to the growth of children.

In recent years, technological developments have been recorded in the field of spinal surgery and these developments have significantly improved the design and function of implants. Especially the development of 3D printing technology has enabled the production of patient-specific and complex implants [2]. Reviews in the literature show that magnetic elongation systems are especially used in the treatment of scoliosis, which causes differences in the alignment and anatomy of the vertebrae [3-8]. The ability to non-invasively adjust the length of the implant is particularly advantageous for children with early-onset scoliosis, as it allows continuous growth without interfering with spinal alignment [6,9]. Magnetically controlled rods have been developed to provide a dynamic solution for spinal deformities. By allowing gradual lengthening through magnetic forces, these devices reduce the need for the multiple invasive surgeries typically required for conventional spinal implants [6].

Magnetic growing spinal rods are designed to allow gradual and controlled lengthening of the spine as the child grows, thus minimizing multiple surgical procedures [10]. Magnetically controlled implants, particularly magnetically controlled growing rods (MCGRs), which play an important role in the treatment of spinal deformities in pediatric patients, have emerged for the treatment of conditions such as early onset scoliosis (EOS) and spinal muscular atrophy (SMA). These implants offer a non-invasive method and reduce the need for repeated surgical interventions traditionally associated with conventional growing rods. While traditional growing rods require invasive surgery for lengthening, MCGRs, which facilitate gradual lengthening of the spinal rod using a magnetic field, allow continuous spinal growth without the need for surgeries [6]. The first successful MCGR implantation occurred in 2009, and the clinical applications and results of studies since then have been documented [11].

II. MATERIALS AND METHOD

In conventional scoliosis treatment, a rod is fixed to the spine. With this method, the spine is fixed by means of a screw-rod system and the system continuously applies corrective force to the spine. In patients with early-onset scoliosis, this procedure must be repeated at certain time intervals due to the incomplete development of the spine. In order to reduce these procedures, the magnetic extensible rod (Fig.1a) was developed. The MCGR consists of a disposable sterile titanium disposable rod with an extended centre section containing a magnetically extending mechanic (Fig.1c). Depending on the size of the patient and the surgeon's preference, single or double rods can be implanted and the size of the rod can be customised according to the patient's height [12].

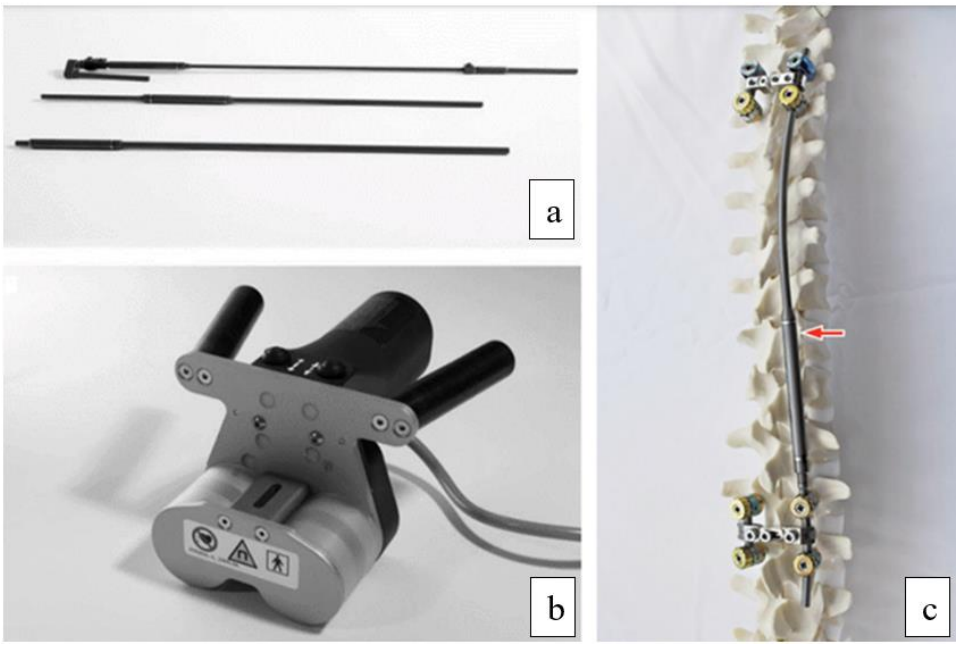

Figure 1. (a) Magnetically controlled extending rod [3], (b) extension apparatus [3] and (c) magnetically controlled extending rod attached to a spine model [13]

In this system, two different titanium rods telescopically move within each other. The magnets in the rod are rotated with the help of the magnetic field given to the body from the outside and thus the length of the rod is changed. Fig. 1b shows the apparatus providing magnetic waves for the extension of this magnetic system. With the magnetic waves created with the help of this apparatus, the magnets in the rod are moved and an elongation is created in the rod. It has been stated that the electromagnetic field exposed during the lengthening process has no side effects on humans [7].

III. DISCUSSION

MCGRs, whose working principle is described in the method section, have been used in the treatment of early-onset scoliosis, a condition characterized by abnormal spinal curvature that can lead to significant morbidity if left untreated. Studies have observed that MCGRs effectively control spinal deformities in young patients and allow thoracic growth, which is crucial for lung development [13,14]. When comparing MCGR and conventional spinal rods, both systems have similar indications. However, MCGRs have been shown to significantly reduce the frequency of surgical interventions and minimize the associated risks and complications [3,16]. Comparing the results of magnetically controlled rod surgery in early-onset scoliosis patients, Helenius et al. found that even severe curves can be treated with this system, although this patient group has higher complication rates [17].

Despite their advantages, complications such as implant failure, infection, need for revision surgery, safety concerns, and mechanical failure of the magnetic mechanism have been reported in the clinical application of these devices [18]. Studies have shown that the likelihood of postoperative infection can be influenced by factors such as the surgical technique used and the underlying health conditions of the patient [19,20]. The complexity of the implantation procedure, which requires precise alignment and positioning to ensure optimal functionality, is also a major problem [21]. Closed anatomical spaces in the spine region also pose challenges for surgeons during the implantation of these devices [22]. Conventional implants need to be applied every two to four months, whereas growing rods only need to be extended every 6-12 months. This results in more frequent exposure to general anaesthesia for conventional implants, with a greater likelihood of side effects [18].

The new generation of programmable lengthening nails, which is a similar system in lengthening treatments, has become quite common. These nails are magnetically extended remotely. The length of the

nails is lengthened by creating fractures in the bones and new bone formations are observed in these gaps[23]. From the same point of view, a magnetic device suitable for mandibular distraction osteogenesis was developed, and the working principle of this device is based on a similar method with other magnetically controlled systems[24]. The available literature shows that this system corrects scoliosis in patients [25]. However, although the results obtained from patients are promising in the short term, long-term results are still lacking [3], [15]. In addition, when the economic effects of magnetically controlled systems are investigated, initial costs are higher due to advanced technology. Research suggests that health care costs due to decreasing rates of surgical intervention may become more favourable over time [3]. Although traditional growing rods initially appear cheaper, it has been shown that the cumulative costs of multiple surgeries and postoperative care may exceed the costs associated with magnetically controlled systems after a few years [3].

IV. CONCLUSION

Magnetic extensible rods (MCGR), a revolutionary development in the treatment of early-onset scoliosis, provide spinal stability and accompany the patient's growth process at the same time. This also reduces the frequency of surgical intervention. The lack of long-term data makes it difficult to predict the future and monitor how the system changes over time. This system, which offers great convenience for both patients and surgeons, is expected to become widespread in the future thanks to developing medical technologies and to become applicable in different orthopaedic disorders and different types of implants. In addition, in the future, it can be integrated with smart implants that provide instant information about the condition inside the body. With remote monitoring, the patient's spine development and treatment process can be controlled more effectively, and even patients can be treated at home thanks to remotely controlled magnetic systems. The development of MCGR technology can be integrated with artificial intelligence and robotic assisted surgery.

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