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Review Paper
Bone Grafting Surgery: A Detailed Review of History

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ABSTRACT

Bone grafting is a surgical procedure, dating back to the Neolithic era. This paper to review the history of bone grafting surgery. The search was conducted in PubMed, Embase, Web of Science and Google scholar databases for any related article, as well as pearling of the references of these papers.

1. Introduction

Bone grafting has a very ancient history and has been linked to myths and beliefs. In Greek mythology, we hear that Gods reconstructed and made a new shoulder for Pelops out of ivory which is a bone xenograft procedure. The creation of Eve from Adam's ribs may be considered as the first isograft in history. There is a painting from a 15th-century unknown artist that depicts transplantation of limbs, including bones, grafted from a recently deceased Moor onto an amputee, based upon what a church retainer had seen in his dreams of the twin martyr surgeons, St Cosmas and St Damian performing this operation [1]. There is evidence from manuscripts back to 2000 B.C. that bone grafting from animals to human has been performed in that time [2, 3], and ancient Egyptians and Aztecs were experts in orthopedic surgeries [3]; however, the first documented bone graft surgery has been reported by Jacob Janszoon van Meekeren from a Dutch, Russian, or British surgeon in 1668 [1, 4-6] or 1682 [7, 8].

He described how a Russian surgeon repaired the defect in the skull of a Russian soldier by transplantation of a piece of bone from a dog's skull. The soldier had

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no problem with the surgery, but was excommunicated by the church and society, because he was thought to be partly dog. Eventually, the soldier asked the surgeon to remove the graft, which it was impossible because of its complete integration into the skull [6]. One hundred fifty years later in 1821, Dr. Von Walter from the University of Bonn, Germany used autograft to fill the bone defects caused by trepanation, first in a dog and then in a human sample. The wound became infected but osseous ingrowth was evident. Adamkiewicz repeated the operation successfully in 1889 [4]. Ten years after the report of Walter, MacEwen from Scotland used the allograft from tibia of a child with rickets for reconstructing the humerus of another child damaged by osteomyelitis [6, 9]. The French surgeon Ollier Léopold (1830-1900), who is the father of experimental bone and joint surgery, used autograft and homologous grafts in his experiments on rabbits and dog [1-3]. He emphasized on the importance of periosteum preservation and recommended the use of only autologous bone graft [4]. According to Orr, in 1859, Ollier transplanted a piece of rabbit bone to a man [10]. Poncet, from Lyon, France (1887) in an attempt to achieve union among non-unions of tibia fracture, transplanted a toe phalanx bone from an amputated leg to the limb; despite the healing of the graft, union was not achieved; it was too small for the purpose [5, 10].

Curtis from New York in 1892 transferred the fibula subcutaneously to a nonunion of tibia. Two months later, the patient could bear weight on the limb [5]. Though Von Eiselsberg in 1901 and Lexe in 1908 used autogenous free bone or pedicled soft tissue and bone of the little finger for the repair of cleft maxilla [10], and despite the works of Ollier and Walter, and the history of vascularised bone grafts, the first bone autograft was invented by Fred Houdlette Albee (1876-1945), a North American surgeon; he performed the surgery for achieving spinal fusion in a patient with tuberculosis in 1909. He wrote the book “Bone graft surgery” in 1915 and published 93 articles about bene grafting during in French, German and Spanish [2, 5, 11, 12]. Georg Axhausen (1877-1960) from Germany and Dallas B. Phemister (1882-1951) from USA described the incorporation of graft from the host organism, and Erich Lexer (1867-1937) reported the clinical results of bone allografting with 20 years of follow-up, obtaining good results in half of patients [1].

When bone grafting is necessary, the most reliable source will be the autologous grafting; however, the complications caused by its removal and the need for large quantity and specific forms of bone make the bone bank a necessity [13]. The idea of preparing and preserving of bone for later use was presented by Bauer in 1910 who reported that, after three weeks of preservation by freezing, allograft bone can be used for transplantation [14]. Tuffier also used frozen bone chips for transplantation in 1911 [14, 15]. Carrel who, published his masterpiece in 1912 and reported his experiments for finding a method to preserve extirpated tissues (including bones) from living animals or fresh cadavers during transplantation using cold storages immersed in ringer solution and plasma [10, 16]. In 1919, Gallie and Robertson reported their experience with the use of boiled beef bone grafts [17, 18]. Orrell in 1938 named the chemically treated bone in his experiments as Os Purum and used it in a series of surgical operations [10, 18]. Inclan in 1942 was the first surgeon who reported use of autogenous bone grafts removed and stored in ringer solution or citrated blood at lower temperatures for varying periods [3, 19].

Orthopedic surgeons in World War II used bones from freshly amputated extremities for treatment of nonunions without encountering problems. The successful preservation of food material at low temperatures led to the idea of homologous bone preservation [18]. Bone bank was received attention when Wilson and Bush showed the technique of allograft bone preservation at temperatures minus 20°C [10, 14, 18, 20]. In 1949, the first human tissue bank “US Navy Tissue Bank” was established which led to founding of the american association of tissue banks (AATB) in 1976.

The bone banks were developed rapidly in Asia and Europe since then. The bone bank, however, has potential challenges: processing may alter the characteristics of bone, cost, laborious preservation, and cause the risk of disease or infection transmission [21].

The need for bone substitutes had been felt from a long time ago. A skull from Neolithic era has been found that shows a piece of gold hammer inserted to repair the defect [3]. Of course, this cannot be considered a bone graft, but certainly is a bone substitute. Dreesman from Germany in 1892 used calcium phosphate (also known as gypsum or plaster of Paris) to fill the defect of six patients with tuberculous osteomyelitis, one patient with enchondroma of fifth finger, and one with osteomyelitis. Three out of 6 tuberculous patients and the patients with enchondroma and osteomyelitis showed good response with extensive bone formation. The remaining three patients with tuberculous cavities, one showed bone formation [22]. Although calcium phosphate worked very well, it was not widely used. Ljubovic and Nikulin (1956) in animal models showed how calcium phosphate worked with healing stimulation and conduction [22, 23]. It was reintroduced to clinical practice by Pel-

tier in 1959 [24] and was examined in many animal and human models [21]. Ultimately, Marshall R Urist (1914-2001) in the 1960s found the bone induction capacity in demineralized bone matrix which led to discovery of a group of proteins named "bone morphogenetic proteins" and started a new era in bone grafting with research on bone substitutes [25-29].

Von Nussbaum in 1875 transferred one half of the comminuted fracture of ulna to repair the 5-cm defect by sliding it into the attached periosteum [4, 5, 30]. However, the first one that used bone transposition on its vascular pedicle was Hahn who in 1884 performed fibula transposition without disturbing blood vessels to the tibia for non-union [31, 32]. Hahn's genius idea inspired Huntington to perform the operation in 1904 [33]. Cole used clavicle with a vascular pedicle of platysma for reconstruction of mandibular defects, but it is unknown how much blood was transferred from this thin muscle [32]. Bardenheuer in 1895 also used a pedicle graft of the mandible to reconstruct it [4, 34] and Ludwig von Rydygier in 1908 reported that he had transferred clavicle on a pedicle of skin to fill a mandibular defect in 1892 [4]. Phlebs in 1891 in two interesting attempts for reconstruction of a defect in tibial nonunion, inserted a piece of bone from a dog into the tibial defect of a boy and attached them to each other for two weeks. The first attempt was unsuccessful; he thought that he would have done biceps tenotomy in the dog; hence, he performed the second operation and observed that the graft had been covered irregularly with new bone and believed that one attempt was needed for achieving union, but the union was not achieved [5, 35].

In 1893, Curtis stated the calcified bone was the most practical material for use in ordinary cases, and the ideal of the future was the insertion of a piece of living bone that can exactly fill the defect [36]. Davies and Taylor used tensor fascia latae accompanying iliac crest to fuse the hip joint, and reported excellent results [32, 37]. Judet reported excellent results for bringing blood to femoral neck non-union via pronator quadratus [38]. Athough Carrel in early 20th Century depicted free tissue transfers [39], transport of bone with its own blood vessels was not performed until the 1970s. In 1974, Ostrup from Sweden performed this transfer in animal models [40] and Taylor in 1975 described fibula transfer for filling defects in human tibia [41]. Since then, multiple pedicular and vascularized grafts have been described and their number is increasing. Despite the advances in bone grafting surgery, the principles and indications have not been changed. Interestingly, the current major indication for bone grafting is the non-union of a fracture and studies are performed on their use and examining their complications [42, 43].

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

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