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W J O

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Contents

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ABOUT COVER

Editorial Board Member of *World Journal of Orthopedics*, Dr. De Martino is an orthopaedic surgeon specializing in adult reconstruction and joint replacement in the Division of Orthopaedic Surgery, Fondazione Policlinico Universitario Agostino Gemelli IRCCS. He completed several fellowships at the Hospital for Special Surgery (New York City, United States) including in Biomechanics, Joint Replacement, Shoulder Surgery, and Complex Joint Reconstruction. In his clinical practice, Dr. De Martino specializes in orthopaedic procedures, including primary and revision total hip, knee and shoulder replacement, and partial knee replacement. He has a strong background in minimally-invasive surgery and new technologies, including robotics and computer-assisted navigation. As recipient of various national and international awards for excellence in clinical research, Dr. De Martino also has a strong research background in orthopedic surgery. (L-Editor: Filipodia)

AIMS AND SCOPE

The primary aim of *World Journal of Orthopedics* (*WJO*, *World J Orthop*) is to provide scholars and readers from various fields of orthopedics with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

WJO mainly publishes articles reporting research results and findings obtained in the field of orthopedics and covering a wide range of topics including arthroscopy, bone trauma, bone tumors, hand and foot surgery, joint surgery, orthopedic trauma, osteoarthropathy, osteoporosis, pediatric orthopedics, spinal diseases, spine surgery, and sports medicine.

INDEXING/ABSTRACTING

The *WJO* is now abstracted and indexed in PubMed, PubMed Central, Emerging Sources Citation Index (Web of Science), Scopus, China National Knowledge Infrastructure (CNKI), China Science and Technology Journal Database (CSTJ), and Superstar Journals Database. The *WJO*'s CiteScore for 2019 is 3.2 and Scopus CiteScore rank 2019: Orthopedics and Sports Medicine is 77/261.

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EDITORIAL

New Year's greeting and overview of *World Journal of Orthopedics* in 2021

Jin-Lei Wang, Massimiliano Leigheb

ORCID number: Jin-Lei Wang 0000-0002-5197-3051; Massimiliano Leigheb 0000-0002-7818-2209.

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Jin-Lei Wang, Editorial Office, Baishideng Publishing Group Inc, Pleasanton, CA 94566, United States

Massimiliano Leigheb, Orthopaedics and Traumatology Unit, "Maggiore della Carità" Hospital, Department of Health Sciences, University of Piemonte Orientale, Novara 28100, Italy

Corresponding author: Jin-Lei Wang, MSc, Director, Editorial Office, Baishideng Publishing Group Inc, 7041 Koll Center Parkway, Suite 160, Pleasanton, CA 94566, United States. j.l.wang@wjgnet.com

Abstract

On behalf of the Editorial Office of *World Journal of Orthopedics* (*WJO*), we extend our sincere gratitude to our authors, subscribers, readers, Editorial Board members, and peer reviewers, thanking each and every one for their contributions to *WJO* in 2020 and with wishes for a Happy New Year. It was the support of all our Editorial Board members and peer reviewers that allowed the Baishideng Publishing Group Inc to successfully carry out the complete peer review, editing and publishing processes for *WJO* in 2020. We have analyzed the data of *WJO*'s manuscript submissions and article publications in 2020, the invited manuscripts for 2021, manuscript peer review, composition of Editorial Board, and citation of *WJO*'s articles, and present the findings here. We expect to be even more productive and to further raise the academic rank of *WJO* in 2021.

Key Words: *World Journal of Orthopedics*; Acknowledgments; New Year's message; Editorial Board; Journal development

Core Tip: With the support of all Editorial Board members and peer reviewers, Baishideng Publishing Group Inc successfully carried out the complete peer review, editing and publishing processes for *World Journal of Orthopedics* (*WJO*) in 2020. We give thanks for their contributions to the *WJO* in 2020 and support their upcoming endeavors to be more productive and to raise the academic rank of *WJO* in 2021.

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INTRODUCTION

As editors of *World Journal of Orthopedics* (*WJO*), we extend our sincere gratitude to our authors, subscribers, readers, Editorial Board members, and peer reviewers, thanking them for their contributions to the *WJO* in 2020 and wishing them a Happy New Year. We also give thanks for the support of all Editorial Board members and peer reviewers, whose efforts allowed for the Baishideng Publishing Group Inc (BPG) to successfully carry out the complete peer review, editing and publishing processes for *WJO* in 2020.

ACADEMIC INFLUENCE OF *WJO*

The *WJO* was launched by the BPG on November 18, 2010, and since then has grown into a high-quality, online, open-access, peer-reviewed journal. While we are celebrating *WJO*'s 11-year anniversary, we are very proud to share with you that since its first publication, *WJO* has published 698 articles that have been cited 8676 times.

In 2020, *WJO* received a total of 154 manuscripts for consideration of publication. Among the 119 which received a first decision by the Science Editor Development Department, 54 were edited and processed and advanced to the second decision, 56 (36.4%, 56/154) were rejected, and 64 (41.6%, 64/154) were published online by the Production Department (Figure 1)[1]. Among the 64 published articles, 18 (28.1%, 18/64) were invited manuscripts and 46 (71.9%, 46/64) were unsolicited manuscripts; in addition, 28 (43.8%, 28/64) were original articles, 19 (29.7%, 19/64) were review articles, 15 (23.4%, 15/64) were case reports, 1 (1.6%, 1/64) was an editorial and 1 (1.6%, 1/64) was 'other' (Figure 2A). The authors of those articles hail from 24 countries or regions. Among them, 14 (21.9%, 14/64) were authored by researchers from the United States, 5 (7.8%, 5/64) from the United Kingdom, 5 (7.8%, 5/64) from the Netherlands, 4 (6.3%, 4/64) from Italy, and 36 (56.3%, 36/64) from other countries or regions (Figure 2B).

As of December 31, 2020, *WJO* has received a total of 204 titles submitted for invited manuscripts for consideration of publication in 2021, including 116 (56.9%) review articles, 80 (39.2%) original articles, and 8 (3.9%) editorials. Among them, 28 (13.7%) had been submitted online and 176 (86.3%) have not been submitted yet (Figure 3).

In 2020, 5609 invitations were sent out to peer reviewers and Editorial Board members to conduct peer review of *WJO* manuscripts, yielding 660 acceptances (11.7%, 660/5609), 603 declines (10.8%, 603/5609), and 4346 non-responses (77.5%, 4346/5609) (Figure 4). Among the peer reviewers and editorial board members who accepted invitations, 224 (33.9%, 224/660) submitted the peer review report on time, 425 (64.4%, 425/660) failed to submit the peer review report on time, and 11 have not submitted the peer review report yet.

The *WJO* Editorial Board is composed of 60 members[2], and the Editorial Office has received 32 new applications to evaluate for inclusion on the member list. The 60 Editorial Board members came from 27 countries or regions. Among them, 10 (16.7%) are from Italy, 6 (10%) from the United States, 4 (6.7%) from Germany, 4 (6.7%) from Iran, 4 (6.7%) from Austria, and 32 (53.3%) from other countries or regions (Figure 5), among which 40 (66.7%) have conducted peer review and 20 (33.3%) have yet to conduct their first peer review.

In 2020, the number of total visits to the *WJO* homepage was about 254463, of which 26.7% of those visits were from the United States, 10.8% from the United Kingdom, and 8.2% from China[3]. The number of total downloads to the *WJO* articles is about 176327, of which 47.9% of those visits have been from the United States, 11.2% from China, and 8.4% from Germany[4] (Figure 6).

As of January 4, 2021, according to data from the Web of Science, the *WJO* published 88 articles in 2018-2019 from authors in 27 countries or regions. Among them, 33 authors (37.5%, 33/88) came from the United States, 12 (13.6%, 13/88) from the United Kingdom, and 7 (8.0%, 7/88) from Italy. These 88 published articles included 83 classified as "article" or "review" and yielded total cites of 190 times in 2020.

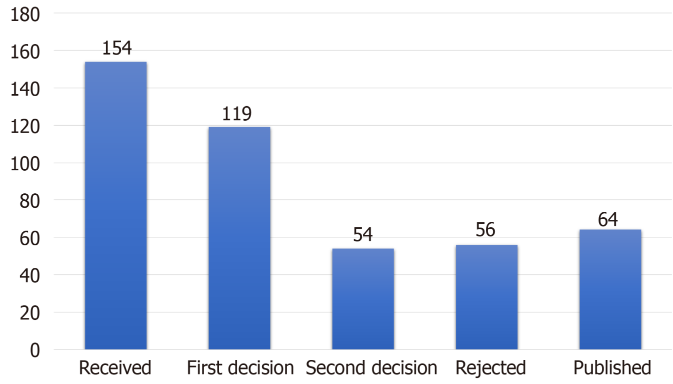

Figure 1 *World Journal of Orthopedics* 2020 manuscript processing. The numbers of manuscripts processed, from submission through publication, are presented.

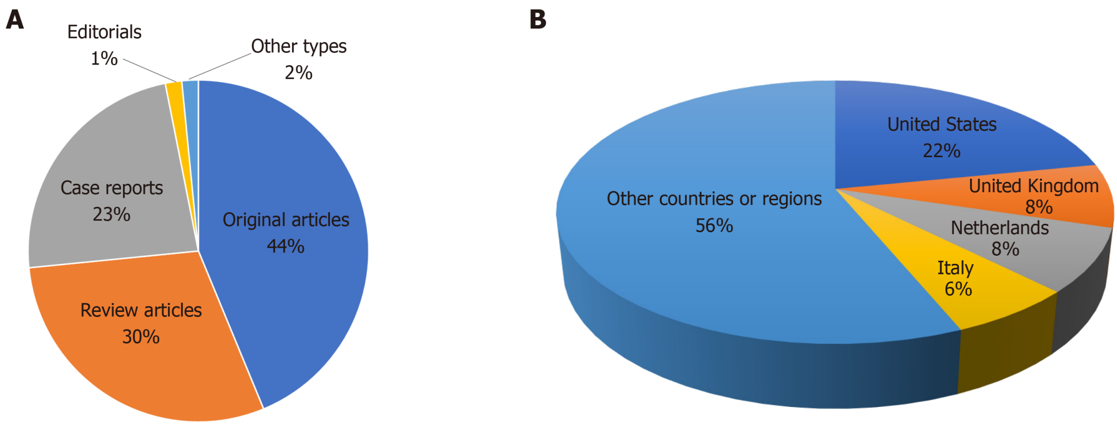

Figure 2 Bibliographic data for articles published by the *World Journal of Orthopedics* in 2020. A: Article types; B: Authors' countries.

According to data from Scopus, the *WJO*'s CiteScore for 2019 is 3.2 and Scopus CiteScore rank 2019: Orthopedics and sports medicine is 77/261 (Figure 7).

CONCLUSION

At present, *WJO* still has some problems to be solved, including: (1) A lower than desired number of manuscript submissions, especially of high-quality original and review manuscripts; (2) A lower than desired number of peer review reports received for each manuscript; (3) The academic quality of published articles should be further improved; (4) A lower than desired number of submissions of invited manuscripts from Editorial Board members; and (5) An insufficient number of Editorial Board members, which presents a challenge to the peer review process for some manuscripts.

With continued dedicated support from all our authors, reviewers, Editorial Board members and readers, we expect to be more productive in this new year. For our part, we commit to working with you all to raise the academic rank of *WJO* in 2021. In order to achieve these goals, we will invite more scientists in the field of orthopedics to join the *WJO* Editorial Board, more active scientists to conduct peer review for *WJO* manuscripts, and more scientists to contribute high-quality original and review manuscripts to *WJO*. By publishing more high-quality articles, the *WJO* will be able to make more substantive contributions to the development of basic medical and clinical research in the field of orthopedics.

We remain open to any suggestions that could improve *WJO*'s operation and publication. Please feel free to contact us at j.l.wang@wjgnet.com, if you have any questions or suggestions on *WJO*.

Once again, on behalf of the Editorial Office of *WJO*, we wish you and your families the best for the New Year.

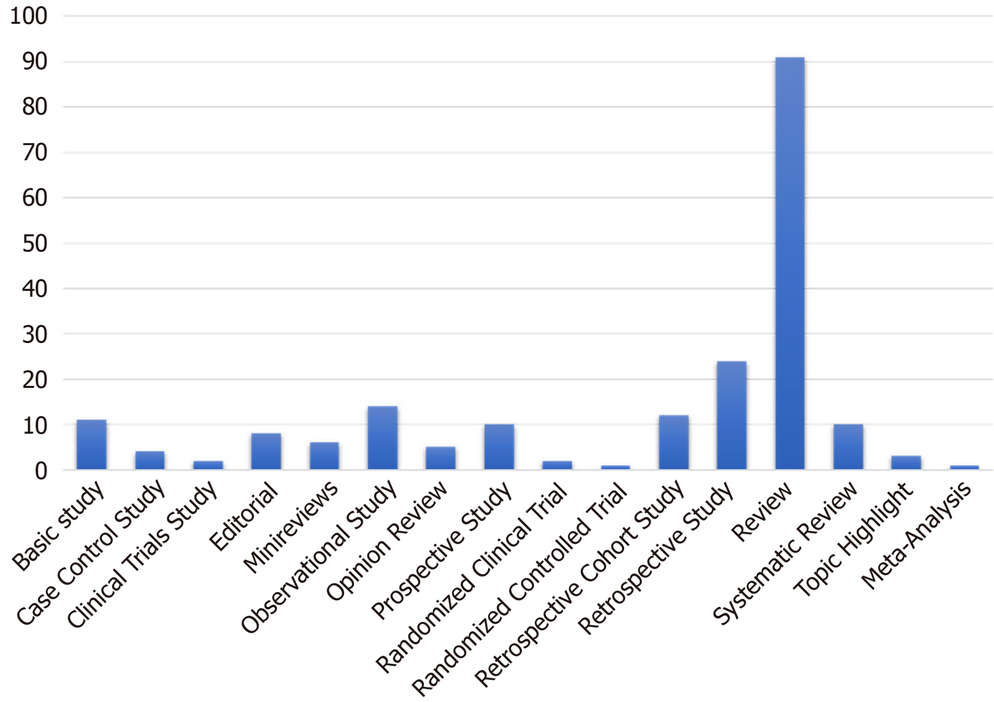

Figure 3 Titles of invited manuscripts submitted for the various types of articles for consideration of publication in 2021 by the *World Journal of Orthopedics*.

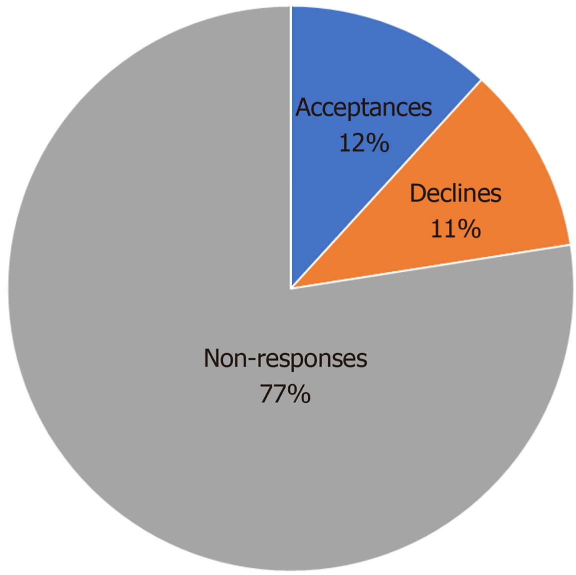

Figure 4 In 2020, 5609 invitations were sent out to peer reviewers and Editorial Board members to conduct peer review of *World Journal of Orthopedics* manuscripts.

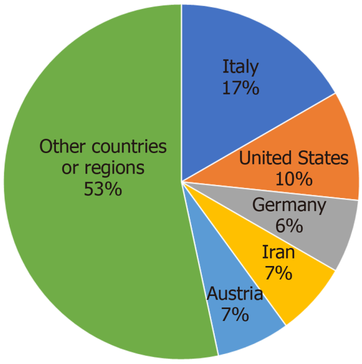

Figure 5 *World Journal of Orthopedics* Editorial Board members are from 27 countries or regions.

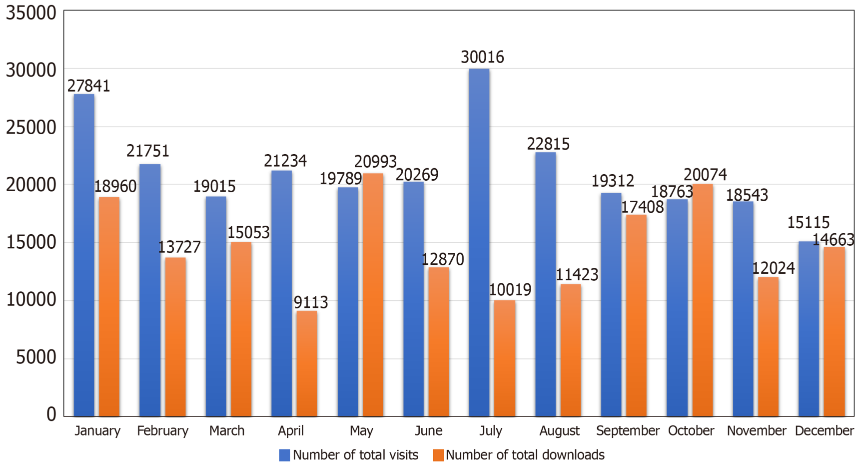

Figure 6 Number of total visits to the *World Journal of Orthopedics* homepage and number of total downloads of *World Journal of Orthopedics* articles in 2020.

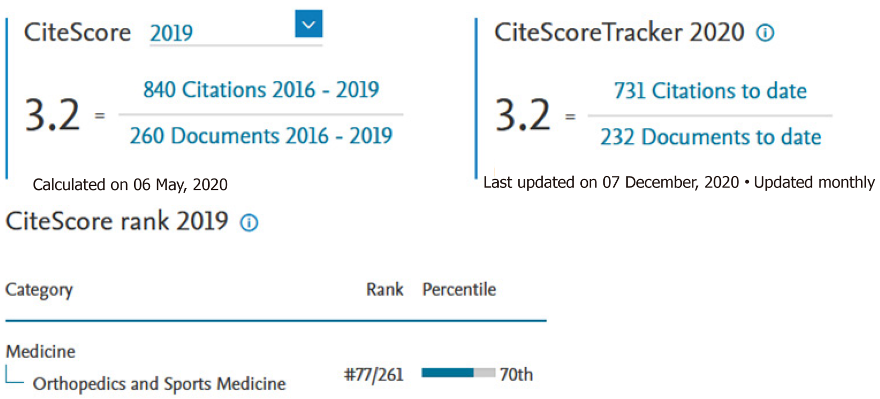

Figure 7 Formula for the anticipated 2019 CiteScore for the *World Journal of Orthopedics.*

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2 **Baishideng Publishing Group Inc**. *World Journal of Orthopedics* Members of the Editorial Board. Available from: https://www.wjgnet.com/2218-5836/editorialboard.htm

3 **Baishideng Publishing Group Inc**. Number of total visits for *World Journal of Orthopedics* homepage. Available from: https://www.wjgnet.com/2218-5836/totalvisits.htm

4 **Baishideng Publishing Group Inc**. Number of downloads for *World Journal of Orthopedics*. Available from: https://www.wjgnet.com/2218-5836/downloads.htm

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MINIREVIEWS

Diabetic foot: Which one comes first, the ulcer or the contracture?

Raden Andri Primadhi, Herry Herman

ORCID number: Raden Andri Primadhi 0000-0002-5825-5941; Herry Herman 0000-0002-0136-9753.

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Raden Andri Primadhi, Herry Herman, Department of Orthopaedics and Traumatology, Universitas Padjadjaran Medical School, Hasan Sadikin Hospital, Bandung 40161, Indonesia

Corresponding author: Raden Andri Primadhi, MD, Assistant Professor, Surgeon, Department of Orthopaedics and Traumatology, Universitas Padjadjaran Medical School, Hasan Sadikin Hospital, Jalan Pasteur 38, Bandung 40161, Indonesia. randri@unpad.ac.id

Abstract

Diabetic foot is among the most common complications of patients with diabetes. One of the known causes of foot ulceration is ankle equinus, which increases the pressure on the plantar surface during ambulation. Conversely, equinus contracture can be caused by a complicated wound, and it may be due to prolonged immobilization. In this paper, we reviewed the pathogenesis of both conditions and their clinical considerations. Poor glycemic control in patients with diabetes may result in angiopathy and neuropathy as an underlying condition. An ulcer can be precipitated by an injury, improper foot care, or increased biomechanical loading as seen in elevated plantar pressure following equinus contracture. Equinus contracture may be a direct effect of hyperglycemia or can arise in combination with another pathway, for example, involving the activation of transforming growth factor β. Static positioning resulting from any prior foot wound may develop fibrotic changes leading to contracture. Wound healing promoting factors can also result in overhealing outcomes such as hypertrophic scarring and fibrosis. The body's repair mechanism during the healing cascade activates repair cells and myofibroblasts, which also serve as the main producers and organizers of the extracellular matrix. Considering this intricate pathogenesis, appropriate interventions are essential for breaking the vicious cycle that may disturb wound healing.

Key Words: Diabetes; Ulcer; Contracture; Vicious cycle; Pathogenesis; Intervention

Core Tip: There is a complex pathogenesis of diabetic foot ulcers, including many variables that are involved in a vicious cycle. This is the first review to analyze the relationship between contracture and ulcer formation, with the aim of formulating a more detailed pathogenesis and timeline for better treatment strategies.

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INTRODUCTION

The rising prevalence of diabetes represents a major public health and socioeconomic burden on society. Diabetic foot is one of the clinical manifestations of diabetes. Diabetic foot may develop in some diabetic patients as a consequence of advanced disease. It is defined as a structural or functional alteration of the foot that may manifest as ulcers, osteomyelitis, or gangrene, as a result of the interaction of different factors induced by sustained hyperglycemia and previous traumatic causes[1,2]. Diabetes-related foot complications have been identified as the single most common cause of morbidity among diabetic patients[3]. Recurrence rates of diabetic foot ulcers are high, and they remain an unresolved issue for many patients[4,5]. Pinpointing the exact cause is difficult; however, this is crucial for the management of diabetic foot as well as for the prevention of recurrences.

Neuropathy, deformity, callus, increased peak plantar pressure, peripheral arterial disease, penetrating trauma, and ill-fitting shoes account for 64% of all new diabetic foot ulcers; hence, their prevention is paramount in comprehensive diabetes management[6,7]. Once it occurs, diabetic foot may be managed with offloading, wound care utilizing various dressings, skin grafting or formal debridement.

One of the common causes of foot ulceration is ankle equinus, which increases the pressures on the plantar surface of the foot during ambulation[8]. Among diabetic patients, contracture of the triceps surae is thought to occur and this contributes to ulcer formation[9]. In patients with a high risk of recurrent ulcers and when traditional offloading methods have failed, surgical offloading may be an alternative option[10-12]. However, equinus resulting from limb contracture is known to be a complication of prolonged static positioning, specifically due to foot wounds, as the ulcer can be initially caused by external injuries as well[13]. In the late stage, it is difficult to determine which one came first: The contracture or the ulceration.

It is not clear in the current literature if the pathophysiology leading to equinus is the same between diabetic and nondiabetic patients[8]. In this paper, we review and analyze the contribution of equinus contracture to diabetic foot ulcers and vice versa. We also sought to formulate the possible timelines of both conditions during the natural course of diabetic foot ulcers.

CLINICAL CONSIDERATIONS

An equinus ankle is an ankle that will not go into more than 5 degrees of dorsiflexion with the knee extended. Most cases of equinus are associated with other biomechanically related disorders[14]. There are several possible causes for the limited range of ankle motion, including a bony block or soft tissue contracture. Limb contracture itself is a condition of shortening and hardening of the muscles, tendons, or other tissues, often leading to deformity and rigidity of the joints. In diabetic foot, contracture may ensue following prolonged immobilization due to the ulcers[13]. This is made worse by macro and microangiopathy, further deteriorating the soft tissue quality.

Initial management of ankle equinus involves stretching and physical therapy, balancing flexibility and power. However, in severe cases, surgery may be chosen to provide an immediate increase in the range of motion[15]. Several surgical techniques have been described. The type and level of surgery will be determined from a physical examination, specifically related to the affected structure. Achilles tendon lengthening is indicated if both the gastrocnemius and soleus are affected. Here, the tendon is either sectioned completely, Z-lengthened, or triply hemisectioned[15,16]. The increase in tendon length will reduce its tension and reduce the pressure on the plantar aspect of the foot by allowing it to dorsiflex. The pressure offloading relieves the abnormal pressure applied to the ulcer, promoting wound healing[17]. Lengthening the triceps surae complex should decrease the stress on the entire plantar forefoot. Lengthening other tendons may serve specific purposes: Peroneus longus tendon lengthening may relieve pressure on the plantar surface of the first metatarsal head, while lengthening of the posterior medial tendon should reduce plantar flexion of the fifth metatarsal head. The literature has attested to the virtue of tendon lengthening when indicated[18]. In addition, correction of static deformity through various methods, including resectional arthroplasty or osteotomy, is beneficial to decrease the pressure overload on the prominences of the plantar surface[19]. Bony correction, such as arthroplasty or excision, may be helpful were deemed necessary. The drawbacks include the changes in the foot anatomy as well as the possible relocation of points of focal pressure to a different area of the foot[20].

PATHOGENESIS OF FOOT ULCERATIONS

Regardless of the anatomical location, the etiology of a diabetic foot wound is considered multifactorial. While the underlying cause is poor glycemic control resulting in angiopathy and neuropathy, the wound can be precipitated by injury, deformities, improper foot care, or elevated plantar pressure due to increased biomechanical loading[21,22].

Diabetic foot development occurs in phases: The first phase is callus formation, followed by multiple foot traumatization due to loss of the protective sensations secondary to neuropathy. Dry skin on the diabetic foot caused by autonomic neuropathy only worsens the condition. The ensuing subcutaneous hemorrhaging delivers the final insult to the skin, resulting in skin ischemia and then ulceration[23].

The presence of localized elevations of plantar pressure has been conclusively identified as the primary determinant of plantar ulceration[24]. Localized increases in pressure are sufficient to initiate ulceration[25]. Tightness or contracture in the triceps surae and foot intrinsic muscles contributes to the initiation of ulceration; triceps surae contracture plantarflexes the foot, increasing stress on the forefoot, while hammertoe and clawtoe resulting in intrinsic tightness cause the migration of the plantar metatarsal head fat[26]. Prior studies demonstrated that plantar pressures are higher in cases with active diabetic foot ulcers despite having a longer stance phase duration, which would be expected to lower plantar pressure. Hence, taking these condition into consideration, the prevention of diabetic foot ulceration requires offloading of pressure during ambulation despite a longer stance phase[27].

Charcot neuropathic osteoarthropathy, for which diabetic neuropathy is the most common etiology, is a condition affecting the bones, joints, and soft tissues of the foot and ankle, characterized by inflammation in the earliest phase. This inflammatory condition may lead to varying degrees and patterns of bone destruction, subluxation, dislocation, or deformity. The hallmark deformity is midfoot collapse, described as a "rocker-bottom" foot, that can result in persistent foot ulceration due to the pressure[28]. The contributing forces for this deformity include the contracture of the peroneal, anterior tibialis, and Achilles tendon.

Biological impairment and vasculopathy also play a significant role in the formation of diabetic foot and its ability to heal. Endothelial dysfunction is an inflammation of the endothelial cells due to hyperglycemia. During the hyperglycemic state, the endothelial cells switch from the utilization of nitric oxide to metabolize glucose, the depletion of which results in the inability to vasodilate. The inability to vasodilate increases intravascular pressure, causing injury and inflammation to the endothelial cells, which in turn causes the migration of inflammatory cells subintimally, forming atherogenic foam cells. Lytic enzymes released by inflammatory cells further damage the vessels in a condition called vasculopathy, which is responsible for both the initiation of ulceration as well as its impaired healing. Impaired activity of the white blood cells involving both B and T cell types in diabetic patients may also complicate the healing and treatment of these wounds[19]. Furthermore, ankle joint equinus has been reported to be associated with diminished venous blood flow in the lower extremity that is detrimental to wound healing[29].

PATHOGENESIS OF EQUINUS CONTRACTURE

Tendon diseases are increasingly common fibrotic disorders and they account for a third of all musculoskeletal complaints[30-32]. Fibrosis itself is characterized by extracellular matrix (ECM) accumulation and often by a change in the quality of the ECM. The morphological and biochemical disturbances of the ECM are directly related to a loss of function in the target organs[33].

In general, several pathophysiologic mechanisms appear to be involved in the development of contracture. The most frequent cause is immobilization, but it can also be caused by congenital deformities, muscle problems, ulcers, local trauma, diabetes, and hormone deficiencies[34]. Prior studies confirmed that levels of physical activity are low in the population with diabetes, and this inactivity is more commonly seen in older patients[35]. This inactivity can lead to contracture development through some conditions, including static positioning, muscle imbalance, and the aforementioned fibrosis.

Static positioning indicates that the position in which a joint is statically positioned influences the number of sarcomeres present in any given muscle. A statically positioned limb developing fibrotic changes within the muscle will develop contracture formation in the position of immobilization. In a supine position, bulky posterior muscles are at a physiologic disadvantage in maintaining flexibility. The imbalance between the flexor and extensor muscle groups has not been shown to be a major factor leading to contracture formation, but contractures are frequently observed when major muscle imbalance is present[13,36]. Thus, inactive patients tend to develop plantarflexion contracture without regular stretching or splinting. Intrinsic muscle tissue alterations in dystrophic myopathies also contribute to contracture formation, due to replacement of the functioning muscle fibers with collagen and fatty tissue in concert with a chronically shortened resting muscle length[13]. A situation of concern is when soft tissue changes that contribute to contractures begin very early after the onset of immobility. Protein synthesis within muscle fibers is reduced within 6 h after immobilization. Shortening of muscle fibers occurs within 24 h, and after 48 h, collagen infiltration of the perimysium is increased[37].

In diabetes patients, chronic hyperglycemia is a major factor causing various complications, since strict glycemic control reduces the end-organ complication incidence and the rate of progression[33]. Hyperglycemia can work through both metabolic and hemodynamic pathways to affect ECM turn-over[33]. Hyperglycemia is responsible for the presence of high levels of advanced glycation end-products (AGEs), which are able to directly stimulate the production of ECM[38]. In addition, AGEs significantly interact with the renin angiotensin aldosterone system (RAAS). Angiotensin II, the main physiological effector molecule of the RAAS, mediates fibrosis by stimulating the synthesis of ECM components. Generally, RAAS is known to be an important contributor to the pathogenesis of diabetic micro- and macrovascular complications by inducing various tissue responses, including not only fibrosis but also vasoconstriction, inflammation, oxidative stress, cell hypertrophy and proliferation[33]. Pathogenesis of fibrosis is also affected by transforming growth factor β (TGF-β). TGF-β regulates the expression of many matrix proteins, including ECM. TGF-β has been previously reported to be the main pro-fibrotic factor in diabetic nephropathy[39]. In the diabetic environment, there is upregulated TGF-β1 expression and bioactivity in glomerular mesangial and proximal tubule cells[33]. Certain comorbidities have been known to affect TGF-β expression, for example, cigarette smoking, in which sustained oxidative stress induces chronic inflammation and causes a further release of active TGF-β1[40].

Our body’s repair mechanism during the healing cascade of the wound may also lead to fibrosis. Activated repair cells, myofibroblasts, are the main producers and organizers of ECM, which is needed to restore tissue integrity after injury. Too many fibroblasts working for too long can cause hypertrophic scarring and tissue contractures[41].

Nonhealing wounds resulting in an infection may cause a stress response in the body by increasing the amount of certain hormones, such as cortisol and adrenaline. In the liver, high cortisol levels increase gluconeogenesis and decrease glycogen synthesis[42]. These hormones work against the action of insulin, and as a result, the body’s production of glucose and blood sugar levels are increased. Inflammatory stimuli that activate macrophages enhance the release of active TGF-β complexes that are secreted by plasma cells and then release active TGF-β into the extracellular fluid[43]. It is well established that TGF-β1 functions as a wound healing promoting factor, and when in excess it may lead to overhealing outcomes, such as hypertrophic scarring and fibrosis[44].

It can be concluded that there are multifactorial etiologies of ankle equinus contracture. Intrinsically, hyperglycemia and wound healing mechanisms are known to play a role in contracture development. In addition, static positioning due to a systemic health problem or the presence of an established wound may result in contracture as well.

CONCLUSION

Diabetic foot ulcer has been known to be associated with various factors, including equinus deformity ensuing from a triceps surae contracture. Although some light has been shed on the mechanism of both, the exact mechanisms and their interactions are still unclear. This is a situation that may seem like a chicken-or-egg condition, and which one comes first is puzzling.

In our experience, the patients came at different stages without any strict pattern of the pathogenesis. Some patients presented ulcers without contracture, and vice versa. It is also suggested not to consider hyperglycemia status as a sole determinant of the ulcerations of contracture development, as it is also depended on many factors as mentioned above.

Determining the timeline of each pathology is crucial, as shown in Figure 1. A contracture may contribute to wound development in the ulcer-prone feet. Recognizing and addressing the source of a triceps surae contracture is important to prevent subsequent ulcers. While chronic hyperglycemia can directly cause contractures through AGEs accumulation, it is not the sole etiology for this condition. Thus, other contributing factors must be identified and taken into consideration. Prolonged immobilization due to diabetic foot is seen as the bridge to triceps surae contracture in nonambulant patients. The body’s wound healing cascade can contribute to further fibrosis that affects the joint. In patients presenting with long-standing wounds, it is difficult to determine which one came first. Thus, a thorough evaluation, including physical and adjunct examinations, must be conducted and interpreted wisely.

Identifying the pathogenesis of a specific pathology can lead to the correct and timely treatment. Assessments and interventions are essential in breaking the vicious cycle that may disturb wound healing.

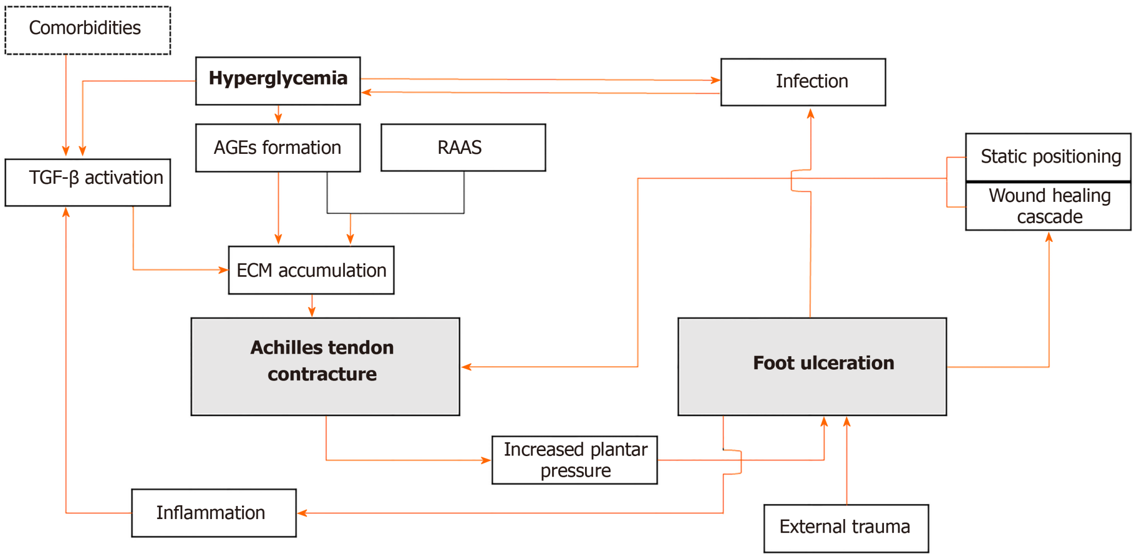

Figure 1 Schematic diagram indicating how a vicious cycle can occur between equinus contracture and foot ulceration in patients with diabetes. TGF-β: Transforming growth factor β; AGEs: Advanced glycation end-products; RAAS: Renin angiotensin aldosterone system; ECM: Extracellular matrix.

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ORIGINAL ARTICLE

Clinical Trials Study

Evaluation of joint awareness after acetabular fracture: Validation of the Forgotten Joint Score according to the COSMIN checklist protocol

Viola Freigang, Johannes Weber, Karolina Mueller, Christian Pfeifer, Michael Worlicek, Volker Alt, Florian Michael Baumann

ORCID number: Viola Freigang 0000-0003-4694-7219; Johannes Weber 0000-0003-4838-9644; Karolina Mueller 0000-0003-4694-7210; Christian Pfeifer 0000-0002-1403-0476; Michael Worlicek 0000-0001-8658-8842; Volker Alt 0000-0003-0208-4650; Florian Michael Baumann 0000-0003-1413-3587.

Author contributions: Freigang V carried out data interpretation, performed literature research and drafted the manuscript; Weber J, Mueller K, Alt V, Pfeifer C and Worlicek M were involved in conduction of the study and significantly participated in preparation of the manuscript; Baumann FM was involved in the design, coordination, and draft of the manuscript; all authors read and approved the final version of the manuscript.

Institutional review board statement: This study was carried out in accordance with the Declaration of Helsinki and approved by the ethics committee at the University of Regensburg in December 2015 (Institutional Review Board Number 15-101-0241). We obtained written informed consent from all study

Viola Freigang, Johannes Weber, Christian Pfeifer, Michael Worlicek, Volker Alt, Florian Michael Baumann, Department of Trauma Surgery, Regensburg University Medical Center, Regensburg 93042, Germany

Karolina Mueller, Center for Clinical Studies, Regensburg University Medical Center, Regensburg 93042, Germany

Corresponding author: Florian Michael Baumann, MD, Associate Professor, Surgeon, Department of Trauma Surgery, Regensburg University Medical Center, Franz-Josef-Strauß-Allee 11, Regensburg 93042, Germany. florian.baumann@ukr.de

Abstract

BACKGROUND

A fracture of the acetabulum is an uncommon, but serious injury. Established outcome tools do not reflect the patient's perspective after fracture of the hip joint. Originally designed for post-arthroplasty patients, the Forgotten Joint Score (FJS) is a patient-reported outcome measurement (PROM) tool evaluating the disease-specific health-related quality of life (HR-QoL).

AIM

To validate the FJS in patients after acetabular fracture.

METHODS

In a prospective mono-centric cohort study, we evaluated 100 patients at mean 5.2 ± 3.6 years after a fracture of the acetabulum. The validation study followed the complete COSMIN checklist protocol. For calculation of convergent validity, we used the Tegner-Activity Scale, the Western Ontario and McMaster Universities Osteoarthritis Index, the EuroQol-5D, and a subjective rating of change as an anchor variable.

RESULTS

We confirmed good internal consistency with a Cronbach's alpha of 0.95. With an intraclass correlation coefficient of 0.99 (95%CI: 0.97, 0.99), test-retest reliability of the FJS was excellent. Correlation coefficients between the questionnaires were moderate to high ranging from |0.56| to |0.83| (absolute value). No relevant

participants.

Clinical trial registration statement: Center for Clinical Studies Registry at University of Regensburg. Registered 01 October 2014, Trial registration number: Z-2014-0389-10.

Informed consent statement: We obtained consent for publication from all study participants.

Conflict-of-interest statement: The authors declare that there is no conflict of interest.

Data sharing statement: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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floor or ceiling effects occurred. Standard error of measurement was 3.2 and smallest detectable change (SDC) was 8.8. Thus, changes greater than 8.8 points between two assessments denote a real change in FJS.

CONCLUSION

The FJS is a valid and reliable tool for evaluation of patient-reported outcome in posttraumatic condition after acetabular fracture. The SDC indicating a real clinical improvement was 8.8 points in the FJS. We could confirm responsiveness of the FJS and found no relevant floor- or ceiling effects.

Key Words: Patient reported outcome measurement; Validation study; Hip joint; Forgotten Joint Score; Acetabulum fracture; COSMIN checklist

Core Tip: A fracture of the acetabulum is a rare but serious medical condition. Patient-reported outcome measurement has rising impact on clinical decision-making and is of extraordinary value in research. Validation of measurement tools is an essential scientific contribution for further research. This study evaluates psychometric properties of the Forgotten Joint Score in posttraumatic condition after acetabular fractures.

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INTRODUCTION

A fracture of the acetabulum is an uncommon but severe injury to the hip joint. Initial management of these injuries is crucial regarding long-term outcome[1-7]. Persistent immobilizing pain and post-traumatic osteoarthritis are typical consequences in cases where the integrity of the acetabulum is not adequately reconstructed. Open reduction and internal fixation (ORIF) is the standard treatment for displaced acetabular fractures. Risk factors for a poor radiographic outcome like residual articular surface gaps and steps as well as involvement of the posterior wall and the quadrilateral surface are well known[2,4,8,9]. However, the impact of these radiographic parameters on Patient-reported outcome (PRO) is unclear. Conventional scoring systems like the Merle d'Aubigne-Postel Score are rather surgeon-based neglecting the patient's perception of the outcome[10].

The "Forgotten Joint Score" (FJS) was developed in 2012 as a PRO measurement tool in patients after arthroplasty of the knee or hip joint[11]. The concept that the patient rates the loss of awareness of the hip joint is revolutionary in patient-reported outcome measurement (PROM). Joint awareness in everyday life is seen as an important criterion in activity of daily living (ADL)[11-13]. The forgotten joint, a condition where the patient has no distracting sensation of the joint, is seen as the ultimate goal resulting in maximum patient satisfaction[11]. Currently, the Merle d'Aubigne-Postel Score and the Western Ontario and McMaster Universities Osteoarthritis Index-Visual Analog Scale (WOMAC-VAS) Score are most frequently used in functional outcome evaluation after acetabular fractures[2,4,8,9,14]. Other scales like the EuroQol-5D (EQ-5D-3L) and the Tegner Activity Scale (TAS) are tools to rate global health-related quality of life and sports activity for characterization of a patient population.

Studies on psychometric properties of outcome tools should meet highest standards regarding methodological quality[15]. The COSMIN checklist is based on an international Delphi study in 2010 reporting on a consensus-based checklist evaluating the quality of studies on psychometric properties of HR-QoL instruments[16]. The COSMIN checklist consists of ten items giving recommen-dations for design, conduction and interpretation of medical validation studies. Relevant characteristics

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are study design, content validity, structural validity, internal consistency, cross-cultural validity/measurement invariance, reliability, measurement error, criterion validity, hypotheses testing for construct validity, and responsiveness.

Purpose of this study was to validate the FJS for mid- and long-term condition after acetabular fractures and to investigate the relation between perioperative parameters and score values of the FJS.

MATERIALS AND METHODS

Validation study

The ethics committee at the University of Regensburg approved this study in December 2015 (Institutional Review Board Number 15-101-0241). We obtained written informed consent from all study participants. The study was carried out in accordance with the Declaration of Helsinki.

In this prospective, mono-centric validating study, we identified 100 consecutive German-speaking patients with a history of an acetabular fracture between 07/2002 and 06/2016.

Inclusion criteria were: (1) Mid- and long-term condition after acetabular fracture; (2) Minimum follow up was 12 mo after trauma; (3) Age between 18 and 70 years; and (4) Sufficient German reading and comprehension capacity.

Exclusion criteria were: (1) Relevant concomitant injuries (*e.g.*, a fracture of the lower extremity or neurovascular injury leading to prolonged immobilization); (2) Preexisting mental disorder; and (3) Lack of consent to participate in this study.

Of initial 296 patients who were treated in a single institution for an acetabular fracture between 07/2002 and 06/2016, 32 patients had died until follow-up, 102 patients were lost to follow-up, 58 patients refused to give their informed consent. Four patients were excluded due to missing data. The patients were asked to complete the questionnaire at follow-up evaluation at mean 5.2 ± 3.6 years after the injury (time point T1). The patients received the questionnaire two weeks after the first questionnaire (time point T2) to evaluate the test-retest reliability and responsiveness. If the patients did not return the questionnaire form within four weeks, the patients were reminded at intervals of two weeks' time. 55 of 100 patients completed the questionnaire twice on average after 32 ± 71.4 d. Figure 1 shows the patient flow chart.

FJS

The Forgotten Joint score is a self-administrated questionnaire comprising of 12 items concerning on the patient's ability to forget the hip joint in everyday life[11]. Meanwhile, the loss of awareness of a joint is seen as the ultimate goal leading to maximum patient satisfaction. The FJS was developed in 2012. Several studies have proven high internal consistency, responsiveness, and construct validity in mid- and long term conditions after arthroplasty[11,13,17-19]. Originally, it was developed to evaluate PRO in patients after arthroplasty of the knee or hip.

The patients were asked to return the forms by mail. For evaluation of test–retest reliability, the patients were supposed to complete a second questionnaire after a minimum of two weeks. The patients received a reminding call if they did not answer within two weeks.

WOMAC-VAS

The WOMAC-VAS is a well-established standardized questionnaire to evaluate the disease-specific health-related quality of life of patients with osteoarthritis of the knee and hip comprising of 24 questions each rated on a VAS (0-100 mm)[20]. Following scores were computed: Subscale pain (0-500 mm), subscale stiffness (0-200 mm), subscale functional limitation (0-1700 mm), and a summary score (0-2400 mm). A WOMAC-VAS score of 0 indicates no pain, no stiffness, and full function. The higher the score is, the more problems the patient is facing. The WOMAC-VAS is validated in German[21].

TAS

The TAS is a well-established score reflecting the patient's highest level of physical activity on a 10 level scale[22]. The TAS is the most commonly reported tool for physical activity in patients with lower extremity disorders. A TAS score of ten reflects the functional capacity of a top-level athlete, a score of 0 reflects the inability to walk. A German adaption is available[23].

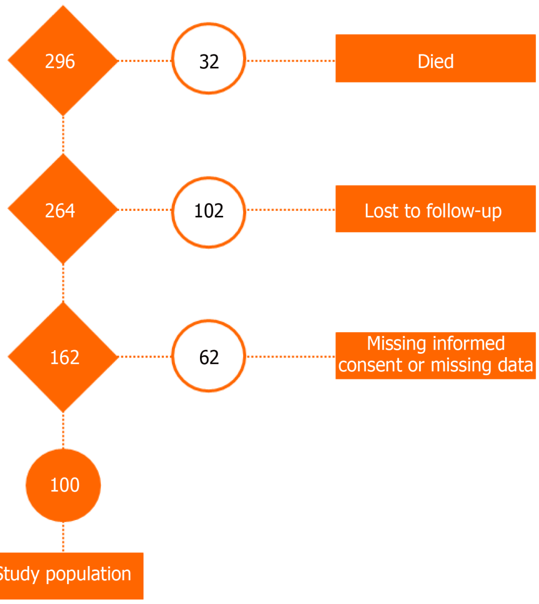

Figure 1 Patient flow-chart of study population.

EQ-5D-3L

The EQ-5D-3L is a HR-QoL questionnaire consisting of subscales regarding mobility, self-care, usual activities, pain/discomfort, and anxiety/depression[24,25]. Responses to each dimension were transformed into EQ index ranging from -0.21 (worst health) to 1.00 (best health). Additionally, the EQ-5D reports the patient's assessment of the current HR-QoL in a 100 mm visual analogue scale. This scale ranges from 0 (the worst health you can imagine) to 100 (the best health you can imagine).

Subjective assessment

We asked the patients to evaluate whether the condition of their hip joint had changed since primary evaluation (much better, somewhat better, unchanged, somewhat worse, much worse). For calculation of the responsiveness, the anchor variable was summarized to 'better', 'unchanged', or 'worse'.

Clinical data

We reviewed all digital patient charts to record relevant clinical data. Our institution is a level-one trauma-center specialized on management of pelvic injuries. Standard diagnostics at time of injury was a clinical evaluation and a computed tomography (CT) scan of the pelvis. The initial degree of initial and postoperative dislocation was rated according to the Matta scoring system for evaluation of dislocation after acetabular fracture[8]. There was an indication for conservative treatment in cases with no relevant dislocation (less than 2 mm and no involvement of the dome area) measured in the initial CT scan. We recorded clinical parameter like treatment modality (operative *vs* non-operative/fracture classification according to Letournel/surgical approach) and compared mean values of the FJS between the groups.

Statistical analysis

Statistical analysis was performed using the software package SPSS (Version 25, SPSS Inc, Chicago, IL, United States). The level of significance was defined at $P < 0.05$ for all tests. Analyses were exploratory, thus no adjustments of P values for multiple testing were conducted. Questionnaires were computed in accordance with guidelines. If not stated in questionnaire guidelines, missing values were not imputed.

Descriptive data were given as frequencies (n) and percentage (%) for categorical variables, mean ± SD or median and interquartile range (IQR) for continuous variables.

Methodological testing according to the COSMIN checklist

We evaluated the reliability (internal consistency, test-retest reliability, and measurement error), validity (convergent validity and clinical validity), responsiveness to change, and interpretability (data completeness and response distribution) of the FJS based on the COSMIN checklist.

Reliability

Reliability is the degree to which the measurement is free from measurement error[16].

Internal consistency

Internal consistency is the degree of interrelatedness among items[16]. Sufficient internal consistency iukrs assumed for a Cronbach's $\alpha \geq 0.70$[15].

Test–retest reliability

Test–retest reliability is the degree of which an outcome of the same patient in the same health condition remains unchanged over time. As the time interval between first and second testing were heterogeneous (0 to 385 d), intraclass correlation coefficient (ICC, two-way mixed model with absolute agreement, average measures) and its 95%CI was estimated indicating an unchanged health condition regarding their hip function compared to the primary evaluation. For an ICC ≥ 0.70 sufficient test-retest reliability was assumed.

Measurement error

The measurement error is the systematic and random error of a patient's score that is not attributed to true changes in the construct to be measured[16]. For patients indicating no change in the condition of their hip joint, standard error of measurement (SEM) and smallest detectable change (SDC) were computed to estimate how much a score needs to change to be sure that a true change has occurred (sensitivity to change). SEM was computed by multiplying the standard deviation (SD, all assessments of patients with unchanged condition) by the square root of 1 minus reliability (ICC): $SD \times (1\text{-}ICC)^{1/2}$. SDC was computed by $SEM \times 1.96 \times 2^{1/2}$[15].

Validity

Validity is the degree to which a questionnaire measures the construct it purports to measure[16]. There is no gold standard in the measurement of PRO. Therefore, we rated validity as convergent and clinical validity. Convergent validity is the degree to which the score of the FJS is comparable with the scores of other functional questionnaires (TAS, WOMAC-VAS, EQ Index, EQ VAS). We measured convergent validity by Spearmen's rank correlation. With a correlation coefficients $|\geq 0.60|$ (absolute value), convergent validity was rated positive. Based on previous results, it is expected that FJS correlates negative and high ≤ -0.60 with WOMAC-VAS subscales and WOMAC-VAS summary score[11], correlates positive and moderate between 0.30 and 0.50 with EQ Index, EQ VAS and TAS[13]. We measured clinical validity of FJS by known-groups comparison using *U*-test to assess differences between patients with and without articular displacement. Just the first FJS measurement of patients without total hip arthroplasty was assessed.

Responsiveness

Responsiveness is the ability of a questionnaire to detect a change over time in the construct to be measured[16]. Changes in FJS were assessed by Wilcoxon tests separate for patients indicating improvement, no change or worsening of hip functioning. Moreover, Cohan's d effect size (ES) was computed for each patient group by the mean difference between measurement at T1 and T2 by the SD of measurement A: mean difference measure A and B/SD measure A. ES values of 0.2, 0.5, and 0.8 indicate small, moderate and large changes/ responsiveness[15,16]. To assess whether patients with different hip function development (improvement, no change, worsening) differed in baseline FJS, Kruskal-Wallis H-Test was computed.

Interpretability

Interpretability is the ability to transform a qualitative effect into a quantitative score[16]. Interpretability of the FJS was assessed by presenting data completeness and response distribution (floor and ceiling effects). Extreme outcome values might not be represented adequately if more than 15% of patients score lowest (0) value (floor effect) or highest (100) (ceiling effect) levels in the FJS. In cases of floor- or ceiling effects, the questionnaire might also not be able to reflect changes[15].

RESULTS

Demographic data

Table 1 shows mean score values at initial assessment and demographic data. The cohort comprised of 79% men and 21% women. All patients had sustained an acetabular fracture 1 to 14 years before. 22% of these patients were treated conservatively; 78% required surgical treatment. Of 78 patients with surgical treatment, 55 patients required open reduction and internal plate fixation. In 37 cases, an anterior approach (25 × ilio-inguinal and 12 × intrapelvic approach) was necessary. 18 patients required posterior fixation *via* a Kocher-Langenbeck approach. We carried out operative management according to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) principles (Figure 2). According to these recommendations, we aimed for anatomic reduction of the articular surface and internal fixation of the fragments. Aftercare was equal for all patients. We advised the patients to partial weight-bearing of 15 kg for 6 weeks and a step-wise increase of load of 10 kg per week until the patient's normal weight was reached. For patients with an involvement of the posterior wall, internal rotation of the hip was limited for 6 weeks postoperative. 54/100 patients had an initial articular surface step of more than 3 mm and 46 patients had an initial articular surface step of 3 mm or less. Regarding long-term complications, 4 of 100 patients required a total hip arthroplasty (THA) due to rapid progressive joint degeneration after the acetabular fracture. There were 2/54 patients in the displacement group and 2/46 patients in the other group requiring THA until follow-up evaluation. The time between accident (T0) and follow-up (T1) was 5.2 ± 3.6 years (range 0.2-13.5). The mean age at follow up (T1) was 57.9 ± 17.6 years (range 22-88). The second questionnaire (T2) was completed on average 31.2 ± 71.4 d (range 0-385) after the first.

Reliability

The internal consistency of the questionnaire is satisfying, with Cronbach's alpha = 0.95 for measurement at T1 (n = 83) and 0.97 for measurement at T2 (n = 50). Even with deleting an item, Cronbach's alpha was high raging between 0.95 and 0.97.

The test-retest reliability was excellent with an ICC = 0.99 (95%CI = 0.97-0.99). We included only patients indicating an unchanged functional condition regarding their hip joint (n = 24).

SEM was 3.2 and SDC was 8.8. Thus, changes > 8.8 points between two assessments denote real change in FJS and changes ≤ 8.8 denote for measurement errors and subject variability.

Validity

In both assessments, convergent validity between FJS and WOMAC-VAS, TAS, EQ Index as well as EQ VAS could be confirmed. Correlation coefficients were moderate to high ranging from |0.56| to |0.83| (absolute value). The higher the WOMAC-VAS (pain, stiffness, functional limitation and summary score), the lower the forgetting of the joint. The higher the TAS, EQ index and EQ VAS, the higher the forgetting of the joint (Table 2).

Clinical validity was assessed by comparing FJS scores between patients with articular displacement (> 3 mm, n = 54) and patients without articular displacement (≤ 3 mm, n = 46). Patients with (median = 3 8.6, IQR = 12.5/72.9) and without (median = 3 7.5, IQR = 16.6/67.8) articular displacement did not differ in FJS at follow-up evaluation T1 (Z = 0.005, P = 0.996).

We also evaluated clinical validity by comparing the different fracture patterns according to the Letournel classification. We found highest median values for anterior column and posterior hemi-transverse fractures (median = 12.5, n = 11), and lowest levels of the FJS in T-type fractures (median = 72.9, n = 3). However, there were only three patients with a T-type fracture within the study population. There was no significant difference in the FJS between the fracture types according to the Letournel classification (P = 0.795).

There was also no significant difference between the surgical approaches (P = 0.477). Lowest FJS levels (median = 15.6, n = 24) were found in patients undergoing ORIF *via* an ilio-inguinal approach whereas patients with a Kocher-Langenbeck approach reported highest FJS levels (median 33.3, n = 18).

There was a significant difference in FJS (P = 0.019) comparing patients after

Table 1 Patient characteristics at initial assessment (T1)

n = 100	Total
Sex	21 female/79 male
Mean age at follow up T1	57.9 ± 17.6 yr
Intra-articular step	54 > 3 mm/46 < 3 mm
Treatment	78 operative/22 conservative
Approach (open reduction only)	37 anterior/18 posterior
FJS	41.4 ± 29.7
WOMAC-VAS	60.6 ± 63.3
EQ-5D Index	0.90 ± 0.09
EQ-5D VAS	67.8 ± 23.0
TAS	3.6 ± 1.8

FJS: Forgotten Joint Score; WOMAC-VAS: Western Ontario and McMaster Universities Osteoarthritis Index-Visual Analog Scale; EQ-5D: EuroQol-5D; TAS: Tegner Activity Scale.

Table 2 Detailed data on correlation of functional scores indicating a positive rating for convergent validity (*r* = Spearmen's rank correlation coefficient) level of significance *P* < 0.05

FJS	WOM I	WOM II	WOM III	WOM total	EQ Index	EQ VAS	TAS
r	-0.69	-0.68	-0.70	-0.73	0.72	0.60	0.56
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
n	96	96	96	96	96	95	94

FJS: Forgotten Joint Score; WOM: Western Ontario and McMaster Universities Osteoarthritis Score; EQ: EuroQol-5D; VAS: Visual Analog Scale; TAS: Tegner Activity Scale.

conservative treatment (median 68.7, *n* = 22) to surgically managed patients (median 33.3, *n* = 78).

Responsiveness

Patients with different hip function development did not significantly differ in FJS at initial assessment ($H_{2,55}$ = 0.336, *P* = 0.845). In patients indicating improvement of hip function, the FJS significantly increased (mean difference = 9.4, *Z* = 3.465, *P* = 0.001, *n* = 21). This increase was higher than the SDC of 8.8 and had a small ES of 0.28. In patients indicating worsening of hip function, the FJS significantly decreased (mean difference = 17.1, *Z* = -2.402, *P* = 0.016, *n* = 10). This decrease was higher than the SDC of 8.8 and had a moderate ES of 0.59. Patients indicating no change in hip function did not show differences in FJS (mean difference = 1.1, *Z* = -0.328, *P* = 0.743, *n* = 24, ES = 0.03). Table 3 presents responsiveness data of the FJS.

Interpretability

The proportion of missing FJS item responses was 3.9% (47/1200) at first assessment and 1.2% (8/660) at second assessment. For four patients, the FJS at first assessment could not be computed as they had more than four missing responses and thus, these patients were excluded from data analyses.

There was no relevant floor effect [minimum score of 0: first assessment T1: *n* = 1 (1%), second assessment T2: *n* = 1 (1%)] and no relevant ceiling effect [maximum score of 100: first assessment T1: *n* = 1 (1%), second assessment T2: *n* = 2 (2%)] for the FJS.

DISCUSSION

The main result of this study is that the FJS is a valid and reliable tool for evaluation of

Table 3 Responsiveness of the Forgotten Joint Score based on the subjective rating of change

	n	FJS first assessment		FJS second assessment		Difference FJS first-second assessment		*P* value	SEM	SDC	ES
		m	SD	m	SD	m	95%CI				
Function improved	21	46.9	34.1	56.2	34.9	-9.4	-13.6–(-5.1)	0.001			0.28
Function unchanged	24	43.8	31.6	42.7	32.6	1.1	-1.9–4.1	0.743	3.2	8.8	0.03
Function worsened	10	37.7	29.0	20.2	13.1	17.1	0.7–33.4	0.016			0.59

FJS: Forgotten Joint Score; SEM: Standard error of measurement; SDC: Smallest detectable change; ES: Effect size.

Figure 2 Initial X-rays of a patient with a both column fracture of the right acetabulum and follow-up X-rays 3.6 years after injury.

PRO in posttraumatic condition after acetabular fracture. The SDC indicating a real clinical improvement after a change of 8.8 points between FJS assessments. We could confirm responsiveness of the FJS and found no relevant floor- or ceiling effects. This is the first study validating FJS in fractures of the hip joint according to the COSMIN checklist.

Study design and patient population

An acetabular fracture is an uncommon but serious injury to the hip joint[2,6,8,9,14,26]. The surgeon-based view on clinical and functional outcomes after acetabular fracture is well documented in literature[1,4,5,26-29]. Operative management has become the standard treatment for displaced fractures[2,6,8,26,28,30]. Even though technical advancements have led to major improvements in management of these injuries, there is still a relevant number of cases leading to poor clinical outcomes[5,6]. The presented outcome studies mainly reflect short-term outcomes with a focus on risk factors leading to early failure with posttraumatic rapid-progressive joint degeneration like quality of reduction or stability of the osteosynthetic fixation[2,4,5,7]. However, there is a variety of symptoms sensed by the patient and the patient's perspective are neglected by most studies on QoL after acetabular fracture[1,2,5,7,8,31]. We chose to include patients with a mid-term result as well as long-term condition in this validating study to represent as many conditions as possible. Demographic data of our patient population is comparable to other studies on acetabular fractures with an average age of 57.9 years at time of injury[2,32,33]. Again, our population represents the broad spectrum regarding age distribution seen in acetabular fracture patients[33]. The FJS was originally designed for patients after arthroplasty of the knee and hip[11]. Therefore, it is compiled for an older, physically less active patient population. However, recent studies have proven reliability in younger patients[12,13,17-19,34]. The FJS measures the patient's ability to forget the joint in everyday life, which is seen as ultimate goal resulting in maximum patient satisfaction[11]. This concept seems to be a valid construct not just post arthroplasty. We found a mean FJS of 41.6 points in our patient population. Recently, Baumann *et al*[34] published a validation study on the FJS in long-term results of patients in a posttraumatic condition after tibial head fracture in 77 skiers. They found an increased joint awareness of 70.7 points in the FJS 9-13 years after injury. The mean score in the present study was 41 at first assessment indicating that the level of forgetting the joint after acetabular fracture is lower than in patients after tibial head fracture (70.7)[13], anterior cruciate ligament repair (70.1)[12] or even total hip arthroplasty (59.8)[11]. We included patients of all age groups and operative and non-operative treatment. The distribution of our population's Letournel classification of acetabular fractures reflects also typical fracture patterns. Therefore, we assume generalizability for this type of injury.

Validation

There is ongoing discussion about methodical standards in validation studies[15,16,35]. The validation process in the present study was processed following the COSMIN checklist[16]. Along with the prospective multicenter design, the study meets high methodological standards with a level of evidence Ib.

The FJS has been validated in English and has been adapted in French, Dutch, Danish, Japanese, and German language[11,13,17,18,35,36]. All of these publications gave a positive rating on internal consistency with a Cronbach's alpha of 0.95-0.97. We measured a Cronbach's alpha of at least 0.95 in our study. According to Terwee *et al*[15] internal consistency can be confirmed if Cronbach's alpha is greater than 0.70 and below 0.95. Greater values reflect higher correlations among the items and might be an indication for a redundancy of two or more items[15]. Cronbach's alpha is also dependent on the number issues a questionnaire contains; higher values for scores with a higher number of items. The FJS consists of only 12 items. Therefore, it seems that the concept of the FJS with measurement of the joint awareness for every question could be the reason for a high level of internal consistency.

Prior studies reported a test-retest reliability of the FJS between 0.80 and 0.97[13,18,36]. We found perfect test-retest reliability with an ICC of 0.99. We intended to include also patients with a long-term result years after injury. In these cases, we assumed a stable medical condition making the ICC robust. The long period of time between time points T1 and T2 in some cases leading to a SD of 71.4 days is a potential source of bias. However, the anchor-based method to include only patients with a subjective steady medical condition should lead to reliable results from a statistical point of view.

We expected the WOMAC-VAS, TAS, and EQ-5D-3L to be appropriate for evaluation of construct validity, because these scores are widely used and a German language version of all scores was validated for sports related injuries and arthroplasty patients[23,24,37]. We decided to use the WOMAC-VAS score as tool for evaluation of validity because it was used in the original publication of the FJS as well[11]. The FJS showed good correlation to the total score of the WOMAC-VAS as well as to the WOMAC-VAS subscales.

To investigate if a risk factors for rapid-progressive joint degeneration like a residual joint surface step of more than 3 mm might have an impact on patient-centered HR-QoL, we collected data from the initial CT scan in cases of conservative treatment and the post-operative CT scan in operatively treated patients. We expected that a complex fracture pattern or a residual articular step would lead to a lower level of forgetting the joint because of inflammation of the joint. However, we did not find any impact of the fracture pattern according to Letournel or an articular surface step of more than 3 mm in the CT scan on the FJS at time of the validation study. This is probably due to the long period mean time between injury and mean follow-up of more than 5 years. It is likely that the patients with a clinically relevant joint step develop joint degeneration within the first two years after injury (n = 4/100). The other patients with an initial articular step might have sustained a consolidation in functional joint kinetics to a sub-clinical degree. From our perspective, this is an interesting finding and is worth further investigating.

However, we did find a difference between surgical and conservative management. Patients after conservative management reported higher levels in the FJS than surgically treated patients. We recommended conservative management with partial weight bearing only in cases with no dislocation of the fragments. We suspect that this reflects a potential selection bias for conservatively treated patients.

Another important issue for the use of PROMs for further prospective trials is responsiveness to change in medical condition. With a lack of gold standard, defining responsiveness is difficult. According to the COSMIN checklist, we assessed responsiveness in patients by Wilcoxon tests and ES[16]. The FJS score has shown good responsiveness in post-arthroplasty conditions longer than 12 mo post-operatively[11,13,38]. In this study, patients indicating no change in function of the hip, FJS scores did not significantly differ, and the mean differences was with 1.1 below the SDC of 8.8. In patients indicating a change in medical condition of the hip, FJS scores significantly differed between both assessments and the mean differences were above the computed SDC. Therefore, we could give a positive rating for responsiveness.

According to the guidelines of the original FJS publication in 2012, we refused to calculate the FJS if more than four items were missing. The overall proportion of missing items of the FJS was 4% at first assessment. Concordant to all prior studies on the FJS, there was no relevant floor- or ceiling effect[11,12,17,18,35,36,38].

Limitations

The findings of this study have to be seen in the light of some limitations. First of all, the limited number of cases. Acetabular fractures are uncommon and treatment is concentrated to large trauma centers. We assume that our population can be seen as reference population for most centers, since our age distribution is relatively broad and we included conservatively and operatively treated patients to reflect clinical reality. Another limitation is that the time span between first and second evaluation showed quite some variability. Although we put major efforts on guidance of the patients to assure highest methodical quality, there is a natural variation in the recorded data. Finally, calculation of ICC was based on only 24 patients. This was the number of patients who indicated no relevant clinical change in medical condition of their hip joint between T1 and T2. Further studies are needed to confirm the results based on longitudinal data.

CONCLUSION

This is the first study validating FJS in fractures of the hip joint according to the COSMIN checklist. The FJS is a valid and reliable tool for evaluation of PRO in posttraumatic condition after acetabular fracture. With a Cronbach's alpha of 0.95, internal consistency of the questionnaire was good. Test-retest reliability was excellent with an ICC of 0.99. Based on the anchor variable, the SDC indicating a real clinical improvement was 8.8 points in the FJS. We could confirm responsiveness of the FJS and found no relevant floor- or ceiling effects. Clinicians are suggested to use the FJS for evaluation of PRO after fractures of the acetabulum.

ARTICLE HIGHLIGHTS

Research background

Patient-reported outcome (PRO) measurement is gaining more and more importance in clinical decision-making. Evaluation of psychometric properties of PRO tools is essential to assure validity.

Research motivation

A fracture of the acetabulum is an uncommon but serious injury. Outcome evaluation tools in patients after acetabular fractures are outdated. However, research based on large registries are dependent on valid outcome tools to allow the comparability.

Research objectives

Aim of the study was to validate the Forgotten Joint Score (FJS) according the COSMIN checklist. The FJS is a novel PRO tool to disease-specific quality of life in musculo-skeletal disorders.

Research methods

The COSMIN checklist is a standard protocol to assure methodical quality of validation studies. The COSMIN checklist consists of ten items giving recommendations for design, conduction and interpretation of medical validation studies. Relevant characteristics are study design, content validity, structural validity, internal consistency, cross-cultural validity/measurement invariance, reliability, measurement error, criterion validity, hypotheses testing for construct validity, and responsiveness.

Research results

We found the FJS to be a valid and reliable tool for evaluation of PRO in posttraumatic condition after an acetabular fracture. With a Cronbach's alpha of 0.95, internal consistency of the questionnaire was good. Test-retest reliability was excellent with an ICC of 0.99. Based on the anchor variable, the smallest detectable change indicating a real clinical improvement was 8.8 points in the FJS. We could confirm responsiveness of the FJS and found no relevant floor- or ceiling effects.

Research conclusions

Clinicians are suggested to use the FJS for evaluation of PRO after fractures of the acetabulum.

Research perspectives

Further studies are needed to confirm the study results, especially concerning longitudinal data. Based on the study results, the FJS can now be used for further clinical studies on post-traumatic conditions after fractures of the acetabulum.

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ORIGINAL ARTICLE

Observational Study

Interobserver and intraobserver agreement for Letournel acetabular fracture classification system using 3-dimensional printed solid models

Eran Keltz, Doron Keshet, Eli Peled, Yoav Zvi, Doron Norman, Yaniv Keren

ORCID number: Eran Keltz 0000-0001-6155-6502; Doron Keshet 0000-0003-2297-6082; Eli Peled 0000-0002-0917-036x; Yoav Zvi 0000-0003-2685-2888; Doron Norman 0000-0001-5690-8139; Yaniv Keren 0000-0002-7708-8472.

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Eran Keltz, Doron Keshet, Eli Peled, Doron Norman, Yaniv Keren, Division of Orthopedic Surgery, Rambam Health Care Campus, Haifa 3525408, Israel

Eran Keltz, Doron Keshet, Eli Peled, Doron Norman, Yaniv Keren, Ruth Rappaport Faculty of Medicine, Technion Israel Institute of Technology, Haifa 3200003, Israel

Yoav Zvi, Department of Orthopaedic Surgery, Montefiore Medical Center, New York, NY 10461, United States

Corresponding author: Eran Keltz, MD, Attending Doctor, Surgeon, Division of Orthopedic Surgery, Rambam Health Care Campus, Ha'Aliya Ha'Shniya 8, Haifa 3525408, Israel. erankeltz@gmail.com

Abstract

BACKGROUND

Acetabular fractures pose diagnostic and surgical challenges. They are classified using the Judet-Letournel system, which is based solely on X-ray. However, computed tomography (CT) imaging is now more widely utilized in diagnosing these injuries. The emergence of 3-dimensional (3-D) printing technology in varying orthopedic fields has provided surgeons a solid model that improves their spatial understanding of complex fractures and ability to plan pre-operatively.

AIM

To evaluate the reliability of the Judet-Letournel classification system of acetabular fractures, when using either CT imaging or 3-D printed models.

METHODS

Seven patients with acetabular fractures underwent pelvic CT imaging, which was then used to create solid, 3-D printed models. Eighteen orthopaedic trauma surgeons responded to questionnaires regarding fracture classification and preferred surgical approach. The same questionnaire was completed using only CT imaging, and two weeks later, using only 3-D printed models. The inter- and intra-observer agreement rates were then analyzed.

RESULTS

Inter-observer agreement rates based on CT imaging or 3-D printed models were moderate for fracture classification: κ = 0.44, κ = 0.55, respectively ($P < 0.001$) and fair for preferred surgical approach: κ = 0.34, κ = 0.29, respectively ($P < 0.005$). Intra-observer agreement rates for fracture classification and preferred surgical approach comparing CT imaging or 3-D printed models were moderate: κ = 0.48, κ = 0.41, respectively. No significant difference in intra-observer agreement was detected when comparing orthopedic pelvic specialists to general orthopedic traumatologists.

CONCLUSION

The Judet-Letournel classification demonstrated only moderate rates of agreement. The use of 3-D printed models increased the inter-observer agreement rates with respect to fracture classification, but decreased it with respect to the preferred surgical approach. This study highlights the role of 3-D printed models in acetabular fractures by improving spatial understanding of these complex injuries, thus providing more reliable fracture diagnoses and alternative viewpoints for pre-operative planning.

Key Words: Acetabulum; Pelvic trauma; Acetabular fracture; Three-dimensional printing; Three-dimensional reconstruction; Judet-Letournel

Core Tip: Three-dimensional (3-D) imaging and printing is an emerging technique in the field of orthopedic surgery. This study highlights the utility of 3-D printing in the treatment of complex acetabular fractures, as it relates to the traditionally used Judet-Letournel classification and the accustomed surgical approaches.

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INTRODUCTION

Acetabular fractures pose a great diagnostic challenge due to the complexity and variability of each fracture pattern. Treatment, whether conservative or surgical, is influenced by the initial diagnosis of the fracture pattern and classification. Therefore, it is essential that these fractures are accurately characterized before decision making[1-4]. The Judet-Letournel classification system for acetabular fractures is the current gold standard for describing these injuries. The system is based on the theory of anterior and posterior walls and columns within the acetabulum[5,6]. Based on this anatomical description, they described five elementary fracture patterns and five associated fracture patterns.

The Judet-Letournel classification system was described using specific pelvic radiographs, termed Judet views, which include iliac oblique and obturator oblique views[5]. However today, most trauma centers perform computed tomography (CT) for high-energy or polytrauma patients. Using these CT scans, three-dimensional (3-D) reconstructions are created, and have become standard diagnostic tools in many trauma centers (Figure 1). Studies have shown that using two-dimensional (2-D) and 3-D CT reconstructions enable improved understanding of fracture patterns and anatomy, in particular with complex pelvic and acetabular fractures[7,8]. Some novel CT-based classification systems have been proposed as well[9], challenging traditional methods.

3-D printing technology can utilize 3-D CT reconstructions to manufacture a tangible model out of a variety of materials, ranging from plastics to metals. This technology is becoming more widespread in various industries, thus making it more affordable and accessible[10,11]. 3-D printing first entered the field of medicine in the

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early 2000s, when dental implants and tailored prostheses were produced. The use of this technology had increased substantially in several areas of medicine, creating anatomic models, prostheses, implants, and other accessories[12,13].

In orthopedic surgery, 3-D printing has been used both for surgical planning as well as patient specific instrumentation (PSI). PSI utilizes 3-D printing to manufacture instrumentation that is unique to a patient's anatomy. Its use has been reported on in varying fields of orthopedics including arthroplasty, orthopedic oncology, trauma, and spine surgery. Several studies have demonstrated that the use of 3-D printed models and implants decreased operative time and improved patient outcomes[14-18].

The reliability of the Judet-Letournel classification has been investigated in several trauma centers. Previous studies evaluating inter-observer agreement of acetabular fractures based on CT scans demonstrated high variability between studies and their reported rates of agreement, with a range of $\kappa = 0.6\text{-}0.7$[7,19-21].

To our knowledge, the use of 3-D printed models to test the reliability of the Judet-Letournel classification system has not yet been reported on in the literature. Therefore, we raised the hypothesis that the use of 3-D printed models of acetabular fractures may improve the interobserver and intraobserver agreement of fracture classification, and influence surgeons' preferred surgical approach.

MATERIALS AND METHODS

Seven patients with varying acetabular fractures that were surgically treated at our institution were included. No initial attempt was made to characterize them according to Letournel's system. Each patient underwent non-contrast CT imaging of the pelvis with 3-D reconstructions. The CT images of each patient were de-identified and assigned a coded number (Figure 2). Each case was stored onto several portable drives and distributed to the reviewing physicians.

3-D printed models of the fractured acetabuli were produced, using a UP Plus 2 3-D printer (PP3DP, United States), using Acrylonitrile Butadiene Styrene (ABS), a chemical compound $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$. Technical limitations mandated a 0.6-0.8/1 ratio of model to real size. The models were engraved with serial numbers (Figure 3). An encoding table was created, with the legend available only to the statistician following data collection. This was a blinded study in that reviewing surgeons were unable to identify which CT scan corresponded to each 3-D printed model.

Eighteen orthopedic trauma surgeons from various hospitals in Israel were selected. Nine of those surgeons specialize in pelvic and acetabular injuries and routinely operate on these injuries. The other nine orthopedic trauma surgeons do not routinely operate on pelvic and acetabular injuries. Each participating surgeon completed the same questionnaire twice. Initial responses were based only off of CT images. They then completed the same questionnaire two weeks later using only the 3-D printed models. They were asked to answer the following two questions: (1) What is the fracture type according to Judet-Letournel classification system? and (2) What is the preferred surgical approach for each case?

Statistical analysis

In order to comply with previous literature, the (Cohen's) Kappa coefficient was used to evaluate Interobserver Agreement between all participants with respect to fracture classification and corresponding preferred surgical approach using either CT images or 3-D printed models. Intraobserver Agreement was also tested for each individual surgeon with respect to fracture classification and corresponding preferred surgical approach using either CT images or 3-D printed models. For each of these parameters a correlation test was performed between the two abovementioned groups of surgeons.

In order to calculate the inter-observer agreement between the various examiners with respect to fracture classification using either CT images or 3-D printed models, we compared each individual's responses to the remaining examiners' responses. This was done for each test that was performed. The number of matches was then correlated to the number of comparisons made (removing duplicate matches), and the results from each imaging method were compared using a Wilcoxon signed-rank test. Statistical analyses were performed using SPSS program (version 20, IBM), with a P value below 0.05 considered significant.

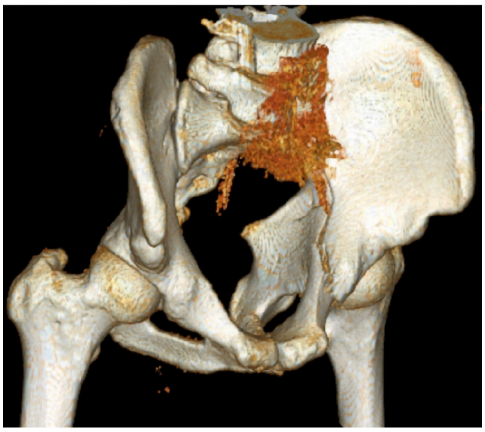

Figure 1 Computed tomography 3-dimensional reconstruction of an acetabular fracture.

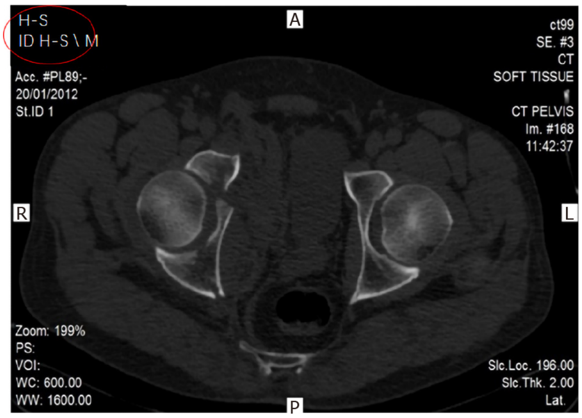

Figure 2 Computed tomography image: an axial cross-section illustrating a right acetabular fracture. Circled in red is the anonymously assigned coding of the case. All identifying details have been omitted from the test.

Figure 3 Three-dimensional printed models of acetabular fractures.

RESULTS

Seven cases of acetabular fractures were selected with differing levels of complexity, at the discretion of the authors. The eighteen participating surgeons examined all CT scans two weeks before the 3-D printed models were examined. The results from all questionnaires are shown in Tables 1-4 and Figures 4 and 5.

The inter-observer agreement regarding fracture classification based on CT and 3-D models was moderate: κ = 0.44 (SE range: 0.0-0.24) and κ = 0.55 (SE range: 0.0-0.22) respectively, with a statistically significant difference between the two modalities (P <

Table 1 Inter-observer agreement on classification, based on computed tomography or 3-dimensional printed models

Fx classification							
		CT			3-D model		
#Surgeon	Match pairs	Mean kappa	SE min	SE max	Mean kappa	SE min	SE max
Mean	153	0.44	0.00	0.24	0.55	0.00	0.22
1	17	0.06	0.06	0.20	0.54	0.17	0.21
10	17	0.22	0.04	0.23	0.41	0.15	0.20
7	17	0.24	0.04	0.20	0.65	0.15	0.22
4	17	0.35	0.06	0.21	0.58	0.15	0.20
12	17	0.36	0.17	0.22	0.26	0.14	0.22
16	17	0.40	0.13	0.22	0.61	0.15	0.20
17	17	0.41	0.11	0.22	0.68	0.15	0.21
14	17	0.42	0.11	0.24	0.60	0.14	0.21
8	17	0.45	0.14	0.22	0.56	0.16	0.20
9	17	0.48	0.10	0.24	0.69	0.00	0.21
6	17	0.50	0.11	0.24	0.54	0.17	0.21
15	17	0.52	0.14	0.22	0.51	0.16	0.21
3	17	0.56	0.11	0.24	0.55	0.15	0.21
11	17	0.57	0.00	0.22	0.69	0.00	0.21
18	17	0.57	0.00	0.22	0.40	0.16	0.21
2	17	0.60	0.00	0.24	0.69	0.00	0.21
5	17	0.60	0.00	0.24	0.44	0.14	0.21
13	17	0.66	0.00	0.24	0.58	0.15	0.20

CT: Computed tomography; 3-D: Three-dimensional; Fx: Fracture.

0.001). The inter-observer agreement regarding the preferred surgical approach based on CT and 3-D models was fair: κ = 0.34 and κ = 0.29 (SE range: 0.0-0.39), with a statistically significant difference between the two modalities (P < 0.005) (Tables 1 and 2, Figure 4).

The intra-observer agreement regarding fracture classification among all 18 surgeons when comparing the two imaging modalities was moderate: κ = 0.48. The surgeons specializing in pelvic and acetabular injuries demonstrated a slightly lower rate of agreement (κ = 0.45) when compared to the general orthopedic trauma specialists (κ = 0.50), though this difference was not statistically significant (P = 0.592). The intra-observer agreement regarding the preferred surgical approach among all the surgeons when comparing the two imaging modalities was moderate: κ = 0.41. The surgeons specializing in pelvic and acetabular injuries demonstrated a lower rate of agreement (κ = 0.37) when compared to the general orthopedic trauma specialists (κ = 0.50), though this difference was also not statistically significant (P = 0.33) (Tables 3 and 4, Figure 5).

After examining the 3-D printed models, surgeons changed their initial responses regarding fracture classification and preferred surgical approach 56 out of 126 times (44%), and 44 out of 126 times (35%), respectively (Table 4). There were no significant differences between the two groups of specialists in this respect (Table 3).

A large variability in responses amongst the cases was evident. For case 2, only three (17%) reviewers changed their decision regarding fracture classification, and only one (6%) reviewer with respect to preferred surgical approach. In contrast, for case 5, fourteen (78%) reviewers changed their response regarding fracture classification, and 9 (50%) reviewers with respect to preferred surgical approach (Table 4).

A total of 70 out of 126 (55.5%) responses regarding fracture classification using CT imaging alone were not changed after examination of the 3-D models. However, in

Table 2 Inter-observer agreement on surgical approach, based on computed tomography or 3-dimensional printed models

Surgical approach							
		CT			3-D Model		
#Surgeon	Match pairs	Mean kappa	SE min	SE max	Mean kappa	SE min	SE max
Mean	153	0.35	0.00	0.39	0.30	0.00	0.39
17	17	0.18	0.17	0.32	0.43	0.00	0.39
12	17	0.18	0.16	0.31	0.09	0.11	0.24
9	17	0.25	0.19	0.31	0.34	0.16	0.36
14	17	0.28	0.16	0.39	0.29	0.15	0.36
15	17	0.31	0.18	0.27	0.25	0.13	0.23
16	17	0.31	0.00	0.36	0.43	0.15	0.35
18	17	0.31	0.00	0.36	0.20	0.17	0.29
10	17	0.32	0.19	0.28	0.19	0.16	0.29
8	17	0.33	0.21	0.30	0.33	0.18	0.24
3	17	0.36	0.18	0.36	0.29	0.17	0.26
2	17	0.36	0.20	0.28	0.35	0.15	0.30
11	17	0.39	0.20	0.27	0.26	0.16	0.28
6	17	0.41	0.18	0.32	0.21	0.19	0.32
1	17	0.41	0.00	0.30	0.43	0.00	0.39
4	17	0.41	0.00	0.30	0.35	0.11	0.26
7	17	0.44	0.20	0.32	0.37	0.19	0.30
5	17	0.50	0.00	0.39	0.24	0.14	0.36
13	17	0.50	0.00	0.39	0.30	0.13	0.39

CT: Computed tomography; 3-D: Three-dimensional.

22.8% of these cases the examiners changed their responses regarding the preferred surgical approach. Of the remaining 56 out of 126 (44.5%) responses that were changed regarding fracture classification, 50% of these surgeons changed their response regarding the preferred surgical approach (Table 4 and Figure 5).

DISCUSSION

The primary outcome of this study demonstrated that 3-D printed models of 7 different acetabular fractures significantly increased inter-observer agreement with respect to fracture classification, while decreasing inter-observer agreement with respect to preferred surgical approach. The use of 3-D printed models did not demonstrate significant difference in intra-observer agreement for both fracture classification and preferred surgical approach. No significant difference in intra-observer agreement for fracture classification and preferred surgical approach was detected when analyzing responses from pelvic and acetabular specialists and general orthopedic traumatologists, separately.

The Judet-Letournel classification system for acetabular fractures is widely used and establishes an algorithm for surgical treatment. This classification system is based on X-ray imaging using Judet views[5]. However, with the prevalent use of CT imaging, most patients with pelvic or actebular injuries are not treated without review of this advanced imaging modality.

Numerous studies have evaluated the reliability and effectiveness of the Judet-Letournel classification system[7,8,19-21], using plain radiographs, 2-D and 3-D CT imaging. We've raised the hypothesis that 3-D printed solid models could contribute to the spatial understanding of these highly complex and variable fractures. The use of

Table 3 Intra-observer agreement on classification and surgical approach, between computed tomography and 3-dimensional printed models

#Surgeon		Fx classification					Surgical approach				
1	1	-0.02					0.70				
2	1	0.50					0.18				
3	1	0.50					0.32				
4	1	0.50					0.55				
5	1	0.83					0.36				
6	1	0.48					0.28				
7	1	0.32					0.77				
8	1	0.66					0.34				
9	1	0.67					0.22				
10	1	0.22					0.40				
11	1	0.50					0.58				
12	1	0.49					0.25				
13	1	0.66					1.00				
14	1	0.50					0.70				
15	1	0.64					0.15				
16	1	0.48					0.19				
17	1	0.32					0.16				
18	1	0.35					0.19				
		Mean	**Median**	**Min**	**Max**	***P* value**	**Mean**	**Median**	**Min**	**Max**	***P* value**
Total	18	0.48	0.50	-0.02	0.83	0.592	0.41	0.33	0.15	1.00	0.331
Pelvis	9	0.45	0.50	-0.02	0.83		0.37	0.25	0.15	1.00	
Trauma	9	0.50	0.50	0.22	0.67		0.45	0.36	0.18	0.77	

3-D printed models affords surgeons a more comprehensive spatial understanding of these injuries, thus improving their ability to plan pre-operatively. Advancement in 3-D printing technology has allowed a relatively simple way to create a real-size detailed model of a fractured acetabulum.

In contrast to previous studies involving a single medical center, this study recruited eighteen surgeons from numerous level 1 trauma centers in the nation, many of who regularly perform complex operations of the acetabulum. Our intention was to provide an accurate and generalizable picture regarding the reliability of the Judet-Letournel classification system. When we asked the surgeons to classify these fractures and provide their preferred surgical approach, our premise was that there is no "correct" answer, and that the agreement rate would be the sole reference.

Tables 1 and 2 demonstrates a moderate rate of agreement regarding the fracture classification based on CT imaging. This rate is lower than reported on previous literature[7,8,10]. One explanation might be that the fractures selected for this study were more complex and difficult to assess. Another explanation is the fact that the participating surgeons work at different medical centers. There's an element of habit and common practice at each medical center, or unified training under the same pelvic specialist, which may create a bias.

The degree of inter-observer agreement for the fracture classification based on the 3-D printed models was found to be only slightly higher, though still moderate. Although both imaging modalities were within moderate agreement, the difference between them was statistically significant (P < 0.001). The higher rate of agreement using the 3-D printed models is likely a result of the improved spatial visualization and understanding of each fracture and the possibility to examine each one from different viewpoints.

The inter-observer agreement rate among all the surgeons regarding the preferred

Table 4 Reviewers' change of decision (computed tomography *vs* 3-dimensional model)

#Surgeon	Total decisions	Fracture classification		Surgical approach	
		Number of decisions changed	% of decisions changed	Number of decisions changed	% of decisions changed
1	7	6	86	1	14
2	7	3	43	4	57
3	7	3	43	3	43
4	7	3	43	2	29
5	7	1	14	2	29
6	7	3	43	3	43
7	7	4	57	1	14
8	7	2	29	3	43
9	7	2	29	3	43
10	7	5	71	3	43
11	7	3	43	2	29
12	7	3	43	3	43
13	7	2	29	0	0
14	7	3	43	1	14
15	7	2	29	4	57
16	7	3	43	3	43
17	7	4	57	3	43
18	7	4	57	3	43
Total	126	56	44	44	35
Pelvis	63	29	46	20	32
Trauma	63	27	43	24	38

surgical approach according to CT imaging (Tables 1 and 2) was found to be fair. This is in contrast to a slightly lower, yet still fair, rate of agreement when using the 3-D models, which was statistical significant (P = 0.005). This can be explained by the fact that different surgeons may decide to approach the same fracture using different methods. Varying personal preferences among each surgeon can explain the lower rate of agreement when compared to that of fracture classifications. The higher agreement rate for the surgical approach when using CT *vs* 3-D models may be due to various options revealed to a surgeon when holding a model in his hand. We believe that, in this respect, use of the 3-D printed models raises a more innovative way of thinking and undermines previous decision making patterns. Simply put, one might say that more information may only contribute to a problem's complexity.

The intra-observer agreement regarding the fracture classification and the preferred surgical approach based on CT imaging *vs* 3-D printed models was moderate (Table 3), with no significant difference between pelvic and trauma specialists in both parameters. Table 4 demonstrates the variance between the cases chosen for the study. It can be assumed that in some cases, the complex fractures posed a greater diagnostic challenge for the reviewers and raised more questions regarding surgical approaches. Another explanation for this can be attributed to technical reasons. Some non-displaced fracture lines, which can be identified through CT imaging, might have been "obliterated" in the printing process and are difficult to identify in the solid models. A higher resolution printer, larger scales, or possibly other modalities (*e.g.*, 3-D holograms) may serve to reduce this effect.

Figure 5 illustrates the surgeons' decision-making process regarding the appropriate surgical approach for each classified fracture, once the 3-D printed models were examined. Although 56% maintained the same fracture classification, 13% of those surgeons decided to change their preferred surgical approach. In our view, this

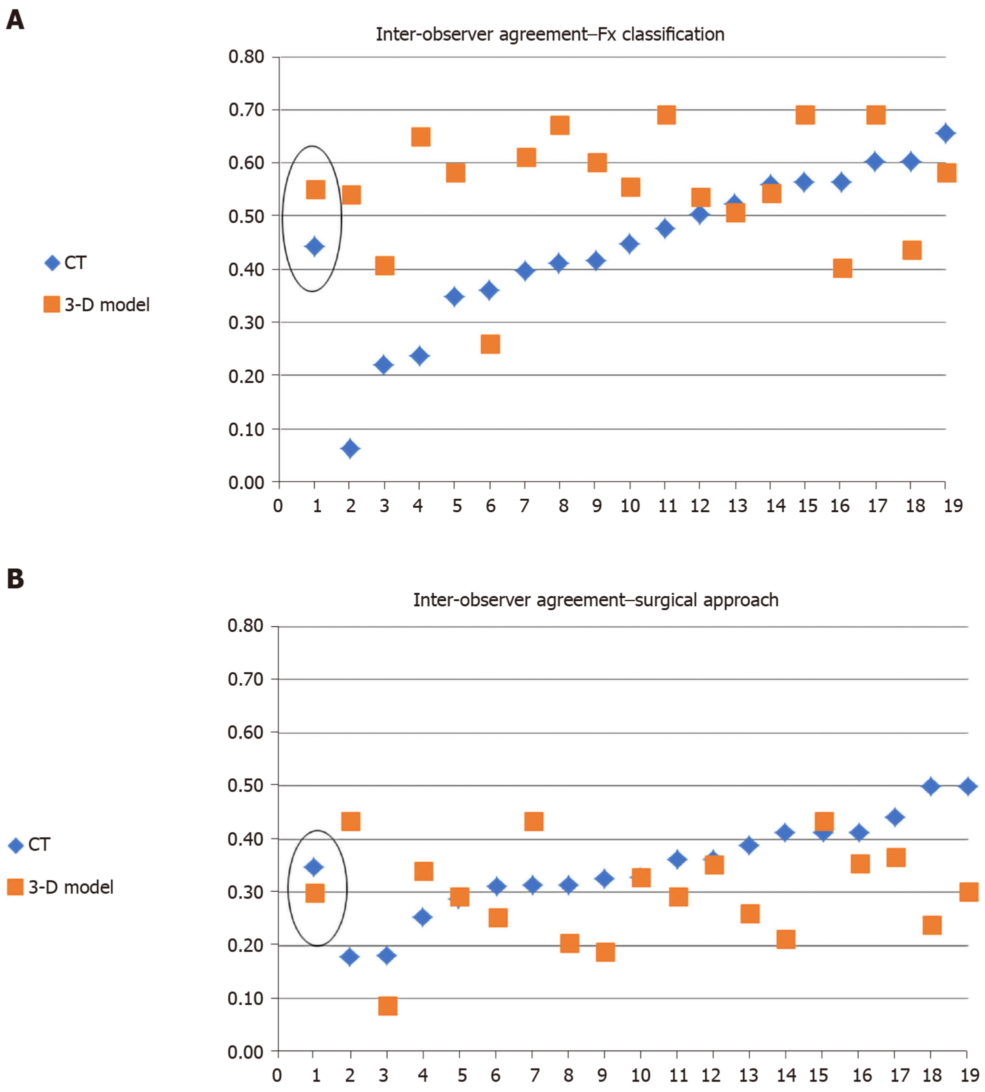

Figure 4 Mean Kappa rate describing agreement between reviewers regarding the fracture classification and preferred surgical approach using computed tomography and 3-dimensional printed models (mean kappa in circle). A: The fracture classification; B: The preferred surgical approach. CT: Computed tomography; 3-D: Three-dimensional; Fx: Fracture.

represents a significant insight into how a fracture is evaluated, and moreover, how it would be addressed surgically. Our findings demonstrate that the Judet-Letournel classification system does not comprise all the information surgeons need for their decision-making. It is likely that the 3-D printed models provide additional information that affects a surgeon's preferred surgical approach.

The collected data did not demonstrate significant differences between the pelvic specialists and general orthopedic traumatologists in all parameters. Presumably, as part of their work, trauma specialists who do not regularly operate on acetabular fractures are still thoroughly familiar with the theoretical material.

CONCLUSION

The results of this study indicate that the currently accepted Judet-Letournel classification system for acetabular fractures demonstrates only moderate rates of agreement by CT imaging alone. Use of 3-D printed models increased the interobserver agreement rates with respect to fracture classification, however decreased the interobserver agreement rates with respect to the preferred surgical approach. Due to the inherent anatomical complexity of acetabular fractures, these models allow for improved visuospatial understanding of these fractures and enable more accurate classification. Additionally, the 3-D printed models allow surgeons to examine a fracture from infinite perspectives and consider the best surgical approach

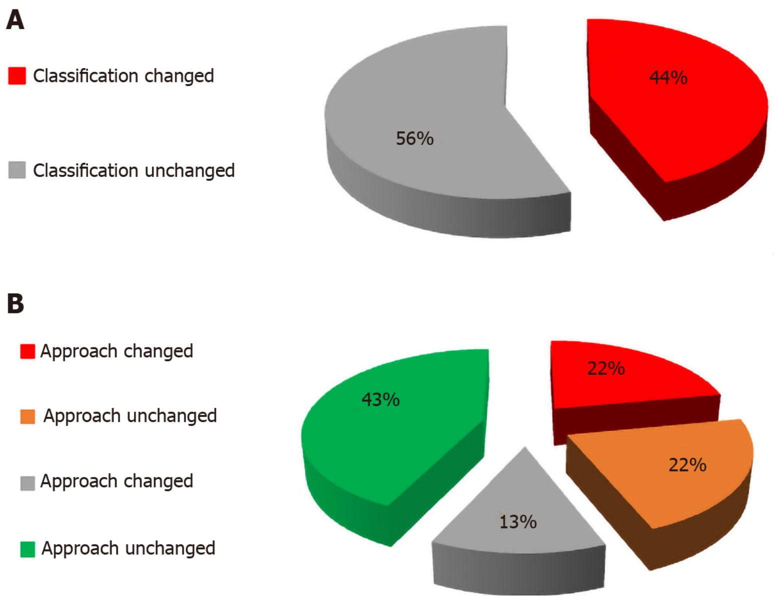

Figure 5 Decision change regarding the surgical approach. A: The effect of reviewing the 3-dimensional model; B: Division of the subgroups demonstrates a change in surgical approach in double rates when the classification is also changed.

before operating. The ability of a surgeon to hold a 3-D model in his hands as part of the preoperative planning process can improve their decision-making. This surgical aid may stimulate renewed thinking of fracture diagnosis and preferred surgical approaches for acetabular fractures, and may contribute to improved surgical outcome.

ARTICLE HIGHLIGHTS

Research background

There are numerous studies examining the reliability of the Judet-Letounel classification system for acetabular fractures using traditional radiographs and computed tomography (CT). However, 3-dimensional (3-D) printing is an emerging technology that hasn't been thoroughly investigated in the field of orthopedics in terms of imaging and pre-operative planning.

Research motivation

We evaluated the intra and inter-observer reliability of the Judet-Letournel classification system, with respect to fracture classification and preferred surgical approach. We compared the use of 3-D printed models of acetabular fractures to the current standard use of CT scans.

Research objectives

The study aims to illustrate the added value of 3-D printed models as a reliable method to more accurately characterize a patient's acetabular fracture, and aid in the decision regarding the preferred surgical approach.

Research methods

Seven patients with acetabular fractures underwent a CT scan with 3-D reconstructions. We then created 3-D printed models of the fractured acetabula. Eighteen trauma surgeons were surveyed to classify each fracture and identify their preferred surgical approach, on two separate occasions, using one of each imaging modality alone.

Research results

The inter-observer agreement regarding fracture classification based on CT and 3-D printed models was moderate for both: $\kappa = 0.44$ (SE range: 0.0-0.24), and $\kappa = 0.55$ (SE range: 0.0-0.22), respectively; this difference was statistically significant ($P < 0.001$).

The inter-observer agreement regarding the preferred surgical approach based on CT and 3-D printed models was fair for both: κ = 0.34, and κ = 0.29 (SE range: 0.0-0.39), respectively; this difference was statistically significant ($P < 0.005$). The intra-observer agreement regarding fracture classification among all 18 surgeons when comparing the two imaging modalities was moderate: κ = 0.48, as for the preferred surgical approach: κ = 0.41.

Research conclusions

3-D printed models improve the inter-observer reliability of the Judet-Letournel classification system, when compared to the use of standard CT scans. However, the inter-observer agreement regarding the surgical approach was decreased, likely due to the added perspective and visualization of the fractures.

Research perspectives

3-D printed models improve visuospatial understanding of complex fractures. Its utility and contribution for better patient outcomes should be investigated in future prospective randomized controlled trials.

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