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EDITORIAL

Use of clinical movement screening tests to predict injury in sport

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Abstract

Clinical movement screening tests are gaining popularity as a means to determine injury risk and to implement training programs to prevent sport injury. While these screens are being used readily in the clinical field, it is only recently that some of these have started to gain attention from a research perspective. This limits applicability and poses questions to the validity, and in some cases the reliability, of the clinical movement tests as they relate to injury prediction, intervention, and prevention. This editorial will review the following clinical movement screening tests: Functional Movement Screen™, Star Excursion Balance Test, Y Balance Test, Drop Jump Screening Test, Landing Error Scoring System, and the Tuck Jump Analysis in regards to test administration, reliability, validity, factors that affect test performance, intervention programs, and usefulness for injury prediction. It is important to review the aforementioned factors for each of these clinical screening tests as this may help clinicians interpret the current body of literature. While each of these screening tests were developed by clinicians based on what appears to be clinical practice, this paper brings to light that this is a need for collaboration between clinicians and researchers to ensure validity of clinically meaningful tests so that they are used appropriately in future clinical practice. Further, this editorial may help to identify where the research is lacking and, thus, drive future research questions in regards to applicability and appropriateness of clinical movement screening tools.

Key words: Functional Movement Screen; Y Balance Test; Star excursion balance test; Tuck jump analysis

Core tip: Clinical movement screening tests like the Functional Movement Screen and Y Balance Test have gained a lot of popularity in the clinical setting as a tool to predict injury and guide injury prevention programs/training. However, clinicians should be aware that various factors like sex differences, previous injury history, and sport participation can influence the accuracy of these screening tests; therefore, it is important to evaluate the validity, reliability, and accuracy of these tools before implementing them into clinical practice.

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INTRODUCTION

Injury is often unavoidable in sport participation and is reported to be as high as 2.51/1000 Athlete-Exposures[1] and 13.79/1000 Athlete-Exposures[2] in high school and collegiate athletes, respectively. These injuries are further classified as overuse, defined as an injury caused by repeated microtrauma without an identifiable event to attribute the mechanism of injury or acute, defined as a specific, identifiable mechanism of injury[3]. Additionally, acute injuries occur as a result of either contact or non-contact mechanisms. Contact mechanisms as defined by the National Collegiate Athletic Association Injury Surveillance System[4] involve direct contact with another player or the playing surface, apparatus/ball, or other in environment (*e.g.,* wall, fence); while non-contact mechanisms are identified as those that occur with no apparent contact and may involve a rotational force. Although these injury distinctions seem to be well understood, the effect of all potential mechanisms is less clear. Several clinical movement screening tests have been proposed to analyze differing mechanisms for injury prediction. Pre-season movement screening tests are likely less effective in predicting contact injuries due to the external mechanism involved with contact injuries. Thus, when comparing between studies one must be cognizant of the operational definition of injury.

Movement screening tools can be used for non-contact injury risk prediction and to guide injury prevention programs; however, the costly nature of sophisticated research equipment is a barrier to using high speed motion analysis in the practicing clinicians' pre-participation physical examinations. Therefore, clinician friendly movement screening tools have been developed and are gaining popularity as a means to reduce injury risk. These tools include the Functional Movement Screen™ (FMS), Y Balance/Star Excursion Balance Test (YBT/SEBT), Tuck Jump Assessment (TJA), Drop Jump Screening Test (DJST), and the Landing Error Scoring System (LESS), which are being used fairly regularly in the clinical setting. Thus, it is important to understand the research surrounding the applicability of these tools to non-contact injury prediction. Therefore, the purpose of this editorial is to define the above clinical movement screening tools and to address each test's normative data, validity, reliability, performance differences across samples, recommendations for use, and injury prediction.

Table 1 Fundamental movement patterns of the Functional Movement Screen™ and the associated clearing tests

Fundamental movement pattern	Clearing test
Deep squat	
Hurdle step[1]	
Inline lunge[1]	
Shoulder mobility[1]	Shoulder impingement test
Active straight leg raise[1]	
Trunk stability push-up	Spinal extension test
Rotatory stability[1]	Spinal flexion test

[1]Performed and scored separately for the right and left side.

FMS™

The FMS (Figure 1) is a clinical test developed to screen performance with fundamental movements, requiring a balance between stability and mobility while moving through a proximal to distal sequence[5]. The FMS is a proprietary tool purported to measure fundamental movements necessary for athletic performance and comprises 7 individual movement patterns and 3 clearing tests, which are tests associated with some movement patterns to determine the presence of pain (Table 1)[5,6]. Each movement pattern is scored based on degree of compensatory movements required to complete the movement, as well as pain. An ordinal scoring system is used from 3-0, where 3 corresponds to the ability to correctly complete the movement without compensation, 2 corresponds to performing the movement with compensation, 1 corresponds to the inability to perform the movement. A score of 0 is given if there is pain during any portion of the movement or pain with the corresponding clearing test. The sum of the 7 movement patterns is used to assess differences between groups and when testing bilaterally the lower score of the two limbs is used for total score calculation (max = 21). Asymmetry is noted in the 5 movements performed bilaterally: Hurdle step, inline lunge, shoulder mobility, active straight leg raise, and rotational stability. Asymmetry is calculated as the absolute difference between the right and left side with each of these movements.

The benefits of the FMS are that it is quick, inexpensive, and easy to administer. This screen is clinically relevant in that minimal equipment and training are required to administer and score the FMS, and a standard testing protocol is readily available[5,6]. The FMS testing takes between 12-15 min to administer and score, making this a viable option for many. The FMS test kit (Functional Movement Systems, Inc., Chatham, VA) is approximately $180.00, making it accessible for a wide variety of clinical and performance settings. Reliable and consistent scoring has been shown with just a 2 h training session[7], again enhancing the use with a variety of fitness and healthcare professionals in different settings.

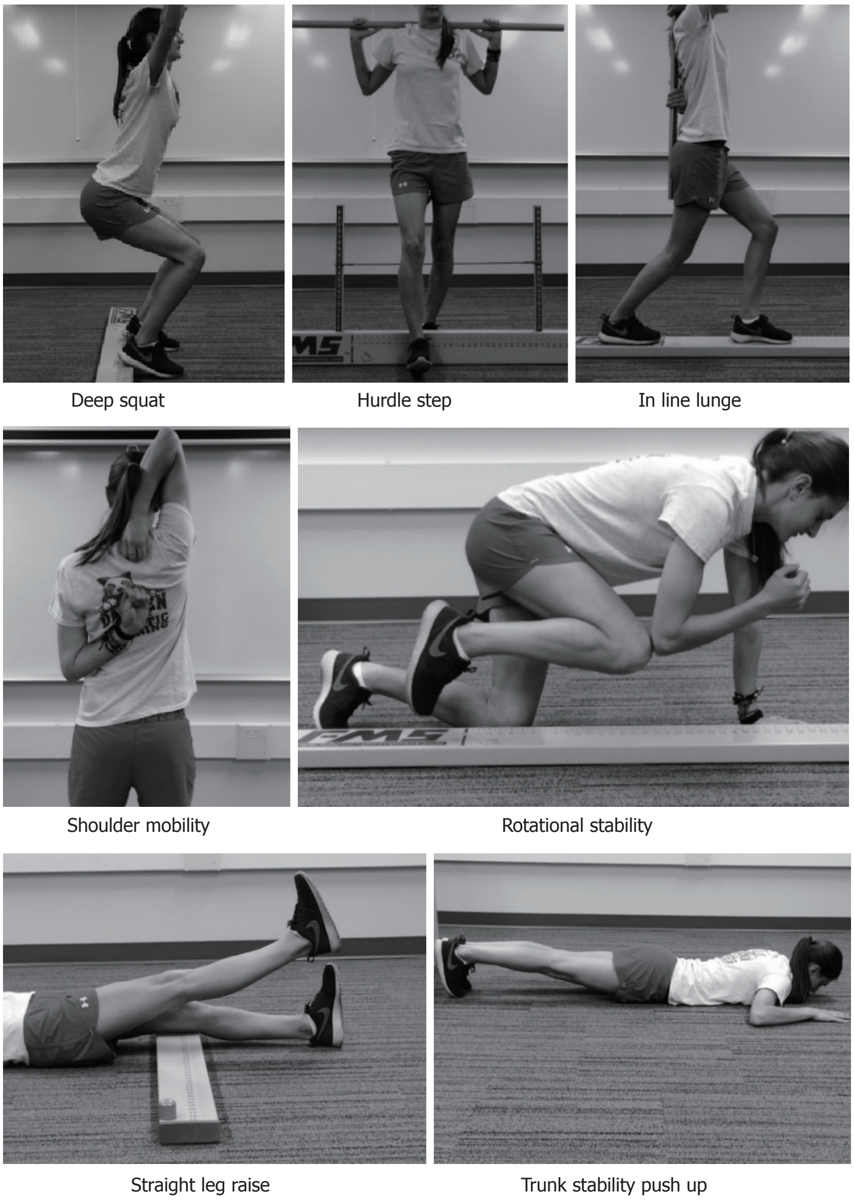

Figure 1 Images of the Functional Movement Screen.

Five studies utilizing varied samples have calculated normative values for the summed total FMS in the last 5 years[8-12]. Two of the studies focused on small samples of participants in specific sports, hurling and Gaelic football (n = 62)[8], and running (n = 43)[9]. The normative value for the total FMS score in both of these studies was very similar (15.6 ± 1.5 for the hurlers and Gaelic football players and 15.4 ± 2.4 in the runners). Teyhen *et al*[11] reported a higher normative value for 247 male and female active service members at 16.2 ± 2.2. There was a significant age by sex interaction (P = 0.007) with higher scores in females and younger ages. The largest sample (n = 622) of 21 years and older included males and females in the general population and reported age and sex stratified FMS scores[10] in general FMS scores decreased with age and females had higher average FMS scores compared with men. Although a large study overall, care should be taken with application of this population-based study since some of the age/sex categories were very small (for example: n = 34 for females 50-54 years old). Finally, normative data in a large (n = 209) sample of 18-40 years old physical active males and females reported an average FMS score of 15.7 ± 1.9[10]. Taken together, for young to mid-life physically active males and females, normative FMS falls between 15.4 and 16.2 points. Lower FMS overall scores were reported for older ages[12]. No differences in overall score between males and females were reported[9,10,13], but sex differences were seen with specific movement patterns[13].

The validity of the FMS has been assessed in several ways. First, for a screening test to be valid it must first be reliable. The reliability has been examined in several studies, and these studies have recently been summarized[14]. Table 2 on Page 3574 gives an excellent summary of the FMS reliability studies[14].

Table 2 Results of studies using Functional Movement Screen™ score of 14 as a cut point to predict musculoskeletal injuries

Ref.	Sample	Injury definition	Sensitivity	Specificity	+LR	-LR
Kiesel *et al*[22]	46 male professional American football players	Athletic performance injury requiring injury reserve and time loss of 3 wk	54%	91%	NR	NR
Chorba *et al*[23]	38 female Division II athletes	Athletic performance injury requiring intervention	58%	74%	2.20	NR
O'Connor *et al*[24]	874 male Officer candidates	Any injury: Physical training injury requiring intervention	45%	78%	NR	NR
		Overuse injury: Long term repetitive energy exchange with cumulative microtrauma	12%	90%	NR	NR
		Serious injury: Physical training injury requiring removal from training	12%	94%	NR	NR
Butler *et al*[25]	108 firefight trainees	Physical training injury with time loss of 3 consecutive days	84%	62%	2.20	0.26
Warren *et al*[26]	195 male and females Division I athletes	Athletic performance injury requiring intervention	54%	46%	NR	NR
Garrison *et al*[27]	160 male and females Division I athletes	Athletic performance injury requiring intervention, and 24 h missed time or splinting, to continue participation	67%	73%	2.51	0.45
Hotta *et al*[28]	84 competitive male runners	Physical training injury with time loss of 4 wk	73%	54%	NR	NR
Knapik *et al*[29]	1045 male and female military cadets	Physical training injury	55%	49%	NR	NR
McGill *et al*[30]	53 elite police officer	Back injury not due to specific acute incidents	28%	76%	NR	NR
		All injury	42%	47%	NR	NR

LR: Likelihood ratio.

Additionally, we previously studied inter- and intra-rater reliability of the FMS after a single 2 h training session[7]. Four raters with different experience with FMS, and education scored 20 recreational athletes (10 males and 10 females) and then re-scored a week later. Two raters were experienced with FMS - one was a Physical Therapy (PT) student, and one was a cross country coach (also FMS certified). The 2 inexperienced FMS administrators were a faculty member in Athletic Training and a PT student. Inter-rater reliability was good for session 1 (ICC = 0.89; 95%CI: 0.80-0.95) and for session 2 (ICC = 0.87; 95%CI: 0.76-0.94). Intra-rater reliability was good for each rater, ranging from 0.81 to 0.91.The conclusions of this study are similar to others who assessed real-time, clinically applicable (*i.e.,* not video recorded) FMS reliability[15-17].

The FMS has good face validity with movement experts (*i.e.,* physical therapists and athletic trainers) as the developers of the screen[5,6]. The content validity is not known for much of the screen. One of the movement patterns - deep squat - has a published biomechanical analysis[18]; it is currently not known what is occurring biomechanically with the other 6 movement patterns. Recently, the inline lunge was compared with measures of power, speed, and balance and no significant correlations were found[19], pointing to the need for further research into what is occurring with each movement pattern.

The FMS has evolved into a single score as a straight summation the scores of the 7 fundamental movement pattern into a single score, ranging from 0-21. In this scoring algorithm, for those patterns performed bilaterally, the lower score of the right and left sides is used, and all patterns are equally weighted. Three of the movement patterns in the FMS (deep squat, hurdle step, and inline lunge) are considered the "big three" with more complex movement patterns[5,6]. The other 4 are considered the "little four" and it is recommended to intervene with these patterns first before addressing the more complex movements. Despite this, the single summative score weights all 7 patterns equally.

The construct validity of a single value has been assessed recently with two factor analyses of the FMS. Kazman *et al*[20] administered the FMS to 934 Marine Officer candidates. With exploratory factor analysis, this study failed to show that FMS score was a unitary construct, calling into question the construct validity for a single score. No interpretable factor was found, and Cronbach's alpha showed low internal consistency; all of the movement patterns had scores below the pre-defined cut-point, suggesting a lack of clustering of the FMS movement patterns. The concept of unidimensionality was further explored in a study of 290 elite Chinese athletes[21]; the results were consistent with Kazman *et al*[20], demonstrating a lack of unitary construct; this suggests that the summed score does not reflect one latent measure or one single result. The authors cautioned about the use of a single summed score, and instead suggested focusing on each movement pattern independently.

The single summed score (dichotomized as less than or equal to 14 *vs* greater than 14) has been reported in several prospective cohort studies about the validity of the FMS to predict musculoskeletal injury (Table 2)[22-30]. Most of the studies reported low sensitivity[22-24,26,29] that is the proportion of the sample who sustained an injury with a score less than or equal to 14 (approximately 50%). This means an equal proportion of the sample who sustained an injury scored above 14 or 14 or less. These studies had a variety of injury definitions and studied samples, including professional and collegiate athletes, and military personnel. Two studies[25,28] reported sensitivity above 70%. Hotta *et al*[28] studied 84 competitive male runners, and with an injury definition of a training related injury resulting in time loss for 4 wk, the sensitivity of the dichotomized FMS score to predict injury was 73%. Butler *et al*[25] reported a sensitivity of 84% for the dichotomized FMS score and injuries related to training and requiring 3 consecutive days of missed training in 108 firefighter trainees. Therefore, perhaps the FMS is more sensitive for predicting more serious injuries requiring time loss from training, although other studies with this injury definition reported low sensitivity[22,24]. The specificity, or the proportion of the studied samples who did not sustain an injury with a FMS score greater than 14 was far more varied, ranging from 46%[26] to 91%[22], so it is difficult to make any definitive conclusions about the specificity. It is evident that there is not a consensus on the ability of the FMS as a single score to predict injury. Part of this is due to the differing samples studied and injury definitions used, as well as the recent studies pointing to the caution with a single FMS score[20,21]. Additionally, several studies reported an inability to find a point on the receiver operator characteristic (ROC) curve that maximized sensitivity and specificity for the studied sample[24,26], and defaulted to 14 as a cut-point based on previously published literature.

Three of the aforementioned studies prospectively assessed the association of each movement pattern with injury[25,26,28]. Butler *et al*[25] reported a significant association between 3 d time loss injuries and deep squat (OR = 1.21; 95%CI: 1.01-1.42) and push-up (OR = 1.30; 95%CI: 1.07-1.53) and Hotta *et al*[28] reported a significant association between 4 wk time loss injury and deep squat and active straight leg raise analyzed together (OR = 9.7; 95%CI: 2.1-44.4). Conversely, Warren *et al*[26] found no significant association between individual movement patterns and injury. It is obvious that further work is required to determine the validity of the FMS to predict injury, either as a summed single score, or perhaps more appropriately as individual movement patterns.

Finally responsiveness, or the ability of an instrument to accurately detect change when it has occurred[31] is closely related to validity and informs the accuracy of an instrument. The ability of the FMS to improve in response to an intervention has been reported in 4 studies of 3 samples[32-35]. In both American football players (n = 62)[35] and mixed martial arts athletes (n = 25)[32], an intervention of corrective exercise was designed based on baseline FMS scores. After 7 wk, the American football players improved the FMS overall score by approximately 3 points (P < 0.001) and had a significant decrease in the number of participants with asymmetrical movements with the 5 bilateral FMS movement patterns (P = 0.01)[35]. Bodden *et al*[32] compared an 8 wk intervention program to a control group and reported a significant time by group interaction (P < 0.001). The intervention group improved overall FMS score by approximately 2 points compared with no change in the control group. The change score reported in both of these studies appears to be consistent with a proposed Minimally Clinically Important Difference of 1.25 for the FMS score[13]. Conversely, a study in 60 firefighters comparing 2 different interventions with a control group found no significant changes in FMS score after a 12 wk intervention (P = 0.18)[33,34]. Additionally, no difference in number of participants with asymmetry was found (P = 0.53).

Despite the popularity, the evidence for the FMS is conflicting, limiting the ability to make definitive recommendations for use. It is a reliable instrument and clinicians should feel comfortable with the consistency of the scoring criteria. Caution should be exercised in using a single summed FMS score or a specific cut-point for injury. As an injury prediction screen, the validity was most accurate with firefighters[25], but firefighters' scores were not responsive to an exercise intervention designed to prevent injury[33,34]. American football players' scores were very responsive to an intervention[35], and despite low sensitivity an FMS score 14 or less was significantly associated with time loss injuries (OR = 1.87; 95%CI: 1.20-2.96)[36]. Additionally, two studies have failed to show a significant difference in FMS scores between injured and uninjured[25,37]. Although there have been over 60 papers published on the accuracy and use of the FMS in the last 5 years, the only clear conclusions are that the FMS is reliable and appears to have good utility in professional American football players as a single summed score. Although this editorial included studies on adults only, there have been a number of studies recently published on the use of FMS in adolescents. Further work is required here to determine if the similar findings occur in adolescents compared with adults.

STAR EXCURSION BALANCE TEST/Y BALANCE TEST

The Star Excursion Balance Test (SEBT) (Figure 2) was first described in the literature for research purposes more than 15 years ago[38]. Since this time a PubMed search shows that approximately 150 publications have utilized this tool for assessing dynamic balance across numerous populations. The SEBT assesses dynamic single leg balance while reaching in 8 reach directions based on the orientation of the stance limb: Anterior, posterior, medial, lateral, anterior lateral, anterior medial, posterior lateral, and posterior medial. The SEBT was first suggested to be modified based on redundancy, as a result of large amount of shared variance, across the 8 reaching directions; this was identified through a factor analysis of SEBT performance in participants with chronic ankle instability[39]. This led to the suggestion of three reach directions, anterior, posterior medial, and posterior lateral rather than

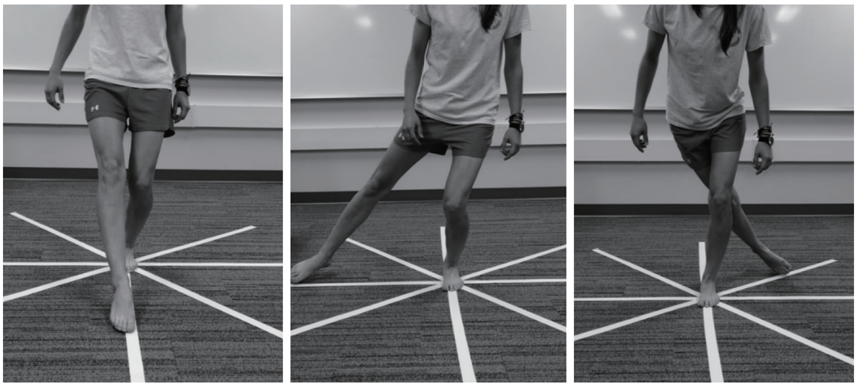

Figure 2 Images of the Star Excursion Balance Test.

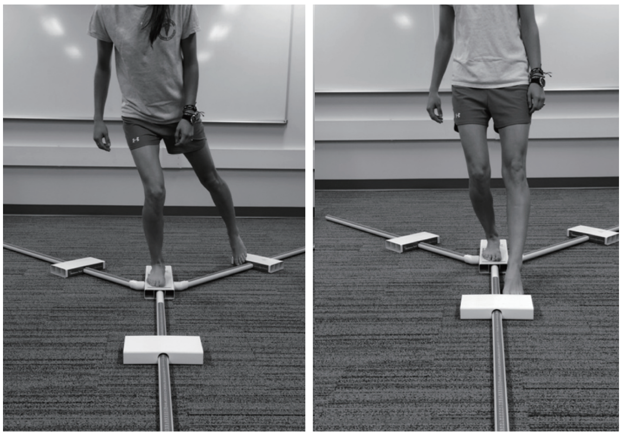

Figure 3 Images of Y Balance Test.

needing to perform all eight from the original SEBT[40].

The SEBT is performed by placing strips of tape on the floor in a grid format while the participant stands in the middle of the grid and reaches as far as possible in one reach direction touching down lightly so the researcher can mark and subsequently measure the reach distance. Trials are considered successful when there is no movement in the stance limb during performance of the SEBT, controlled motion while maintaining balance, and returning of the reaching limb back to the starting point[39]. The Y Balance Test (YBT) (Figure 3), an instrumented, proprietary version of the modified three reach SEBT, first appeared in the literature in 2009 with the intent of improving test repeatability[41]. This device is made of PVC piping and has a center platform the participant stands on while reaching with the contralateral limb and lightly pushing a reach indicator as far as possible along a PVC piping tube. Scoring for both the modified SEBT and YBT involve determining the farthest reach in each of the three reach directions (anterior, posteromedial, and posterolateral) and creating a normalized composite reach score (CS), a normalized single direction reach, and/or a single reach direction asymmetry measurement. The normalized (by participant's leg length) reach distance has been recommended for comparison because performance differences may be a result of anthropometric characteristics[42]. The normalized CS, expressed as a percent, is calculated by averaging the maximum reach in each of the three reach directions, dividing this number by 3 times leg length (LL)[43]. The normalized single reach direction is also expressed as a percent, and is calculated by taking the maximum reach in the single reach direction, dividing this number by LL[42]. The single reach direction asymmetry measurement is calculated as the absolute difference in centimeters between the right and left limb for a single reach direction[43].

A review of the literature suggests that inter-rater reliability of the YBT is slightly higher than the SEBT for the normalized reach distances [ICC 0.99-1.00 (95%CI: 0.92-1.0)[41] *vs* 0.89-0.94 (95%CI: 0.80-0.95)][44] and the CS [ICC range 0.97-0.99 (95%CI: 0.92-0.99)[41] *vs* 0.92 (95%CI: 0.85-0.96)][42]; it should be noted that both the YBT and SEBT have very good inter-rater reliability. Intra-rater reliability appears similar between the YBT normalized reach directions [ICC range = 0.85-0.91 (95%CI: 0.64-0.95)][41] and the SEBT (ICC range = 0.84-0.92; 95%CI: not reported)[45]. For the YBT CS, Plisky *et al*[41] reported intra-rater reliability to be high (0.91 95%CI: 0.69-0.96); however, Munro *et al*[45] did not report the ICC for the SEBT CS; therefore, a direct comparison of intra-rater reliability for the CS cannot be made between the YBT and SEBT.

While it appears that using an instrumented device to measure dynamic balance (*i.e.*, YBT), may have a higher overall reliability, there is one main difference in the protocols between the YBT[41] and SEBT[38]. The YBT allows for stance foot movement during performance of dynamic reaching. Although this may seem like a subtle difference in protocol, there have been two studies to date that have found differences in performance and kinematics during a direct comparison of the YBT and SEBT performance[46,47]. Participants reached further in SEBT anterior reach compared to YBT anterior reach[46]; while utilizing less hip flexion[47]. The development of the YBT was based on the SEBT; however, differences in performance may suggest that these two tests are not as similar as previously thought and that there needs to be more research to assess neuromuscular differences between these two dynamic balance tools before assuming that findings from the SEBT translate to the YBT.

The normalized reach distance, composite score, and reach distance asymmetry may seem like reasonable means for comparing the SEBT and YBT performance, little attention has been dedicated to the validity of these measurements. In fact, a factor analysis has yet to be performed. Interestingly, dynamic balance differences have been noted between sexes[13,48], ages[49], countries of origin[50], sport participation[51], and sport level[52]. Further, Lehr *et al*[53] assessed risk of noncontact injury based on YBT performance in 183 Division Ⅲ athletes from 10 NCAA sports teams and recommended that injury risk should be based on sport, sex, and age.

Despite the numerous publications involving the use of the SEBT and the YBT, there are only 4 published studies that have used one of these tools to determine sport injury risk. In a study on lower extremity non-contact injury risk in high school athletes, Plisky *et al*[43] demonstrated that a CS of less than 94% LL resulted in a 6.5 times greater odds (95%CI: 2.4-17.5) of lower extremity injury female high school athletes and an anterior reach asymmetry of more than 4cm resulted in a 2.7 times greater odds (95%CI: 1.4-5.3) of lower extremity injury in all high school athletes (n = 235; 30 boys, 105 girls). Butler *et al*[54] found that lower extremity noncontact injury risk was 3.5% higher (95%CI: 2.4-5.3) in collegiate Division Ⅲ football players (n = 59) with a CS of less than 89.6% LL. In this study ROC analysis revealed that a composite score 89.6% LL maximized sensitivity (100%) and specificity (71.7%); however, ROC analysis of reach asymmetry did not find an ideal cut point for identifying injury risk[54]. Conversely, Smith *et al*[55] also used the YBT to assess risk of injury based on YBT performance in 184 Division Ⅰ athletes from 13 NCAA sports teams and found that noncontact injury was associated with 4 or more cm of anterior reach asymmetry (OR = 2.33; 95%CI: 1.15-4.76). This study used an ROC curve and determined that 4 cm was the optimal cut point (sensitivity: 59%; specificity: 72%) for predicting injury; interestingly, ROC curve failed to maximize sensitivity and specificity for composite score; there was no relationship between CS and injury[55]. Lastly, Olivier *et al*[56] found no difference in SEBT composite score between cricket pace bowlers who sustained lower extremity injury and those that did not (n = 32, 17 injured-left leg: 79.65% LL *vs* 83.26% LL; P = 0.16; right leg: 78.70% LL *vs* 81.59% LL; P = 0.18); however, those who were injured performed significantly worse on the normalized posteromedial reach direction than those who were not injured (90.07% LL *vs* 91.26% LL; P = 0.02). In this study of cricket pace bowlers all injuries that resulted in time loss of at least one day or required the bowler to quit activity in which they had already started was included; this implies that all injuries were included rather than just non-contact injuries. Additionally, the authors did not report reach asymmetry differences in this study, which combined with the inclusion of all injuries, makes comparison between this and previous studies difficult. It should be noted that the CS in the cricket bowling study[56] were lower than those reported in the previous studies in which noncontact injury was associated with CS performance of lower than 94%[43] or 89.6%[54].

To date 7 studies have evaluated the effects of dorsiflexion range of motion[57,58], sex and injury history[13], and interventions on SEBT/YBT performance[59-62]. Forty-five individuals (12 males; 33 females with chronic ankle instability and reduced dorsiflexion range of motion had significant, but low positive correlations with performance on the SEBT CS (r = 0.30, r^2 = 0.09, P = 0.02) and normalized anterior (r = 0.55, r^2 = 0.31, P < 0.001) and posterolateral (r = 0.29, r^2 = 0.09, P = 0.03) reach[57]. Further, Hoch *et al*[58] reported that dorsiflexion range of motion as measured by the weight bearing lunge test (n = 35; 14 males; 21 females) explained 28% of the variance in the normalized anterior reach of the SEBT leading the authors to suggest that the anterior reach of the SEBT may be a good test to determine the effects of dorsiflexion limitations on dynamic balance performance. While it does not appear that males (n =103) and females (n = 87) perform differently on YBT CS (102% ± 8% *vs* 100% ± 6%; P = 0.05), males have been reported to have a significantly greater anterior reach asymmetry compared to females (4.4 ± 6.7 cm *vs* 2.7 ± 2.3 cm; P = 0.02)[13]. Additionally, one study indicated that history of injury or surgery did not affect YBT CS or asymmetry; however, those who reported a back or trunk injury had greater variability in asymmetry in the anterior and posterior medial reach directions[13]. This finding is particularly interesting as trunk stability exercises (front plank, quadruped, and back bridges) have been demonstrated to provide immediate improvement in normalized SEBT CS (94.0% ± 4.8% *vs* 96.8% ± 5.7%; P < 0.001) and posterolateral (102.8% ± 7.3% *vs* 106.2% ± 8.1%; P = 0.002) and posteromedial (105.3% ± 5.8% *vs* 109.8% ± 6.4%; P < 0.001) reach directions (n = 11)[59]. Additionally, after 12 wk of trunk stability exercises, 27 soccer players demonstrated improvement in normalized posteromedial (101.5% ± 7.2% *vs* 110.0% ± 9.3%; P = 0.013) and posterolateral (96.2% ± 12.9% *vs* 104.7% ± 8.1%; P = 0.02)[60]; while an 8 wk lower extremity neuromuscular training program focused on core stability and lower extremity strength improved SEBT CS (right: Pre-training-96.4% ± 11.7% *vs* post-training-104.6% ± 6.1%; P = 0.03; left: Pre-training-96.9% ± 10.1%; post-training: 103.4% ± 8.0%; P = 0.04) in 20 uninjured soccer players (13 experimental; 7 control)[61]. Interestingly, Ambegaonkar *et al*[63] found that hip strength, rather than core endurance (McGill's Core Endurance Tests), was associated with SEBT performance in 40 collegiate female lacrosse and soccer athletes. Additionally, Garrison *et al*[62] reported a significant decrease in

Figure 4 Images of the Drop Jump Screening Test. Participants drop off of the box and upon landing on the ground they are asked to immediately explode up in to a vertical jump. Image is at max height of vertical jump.

anterior reach asymmetry tested with the YBT in participants with ACL reconstruction after 12 wk of a traditional rehabilitation plus isolated hip strengthening rehabilitation (n = 22) compared to those in traditional rehabilitation (n = 21) only (2.7 ± 2.9 *vs* 6.1 ± 4.6; P = 0.008).

These differences between groups and studies may suggest the types of analytic comparisons currently being conducted to determine differences between groups when performing the YBT/SEBT may not fully capture the risk of injury attributable to dynamic balance performance. In taking into consideration all of the studies presented here it appears that anterior reach asymmetry is most affected in terms of sex differences and dorsiflexion range of motion; while core training appears to help mitigate performance differences. Additional research is needed in regards to the CS as there are differences in the maximized cut-point to use for injury prediction; however anterior reach asymmetry of 4 or more cm appears to consistently predict non-contact injury risk. It is also important to consider that there are a number of factors that contribute to dynamic balance performance and thus may need to be accounted for when assessing injury risk based on lower extremity dynamic balance.

DROP JUMP TEST

The Drop Jump Test (Figure 4) has been described in the literature as a tool to evaluate landing patterns from a clinical perspective using either the DJST or the LESS.

DJST

The DJST is a clinical used to assess dynamic knee valgus on landing from a 30.48 cm height and immediately exploding into a vertical jump *via* a simple frontal plane video analysis of normalized knee joint separation distance (calculated as knee separation distance/hip separation distance); it was first described in the literature approximately 10 years ago[64]. This tool was designed based on the group's prior work[65], which assessed landing mechanics in youth athletes[64]. This test uses reflective markers placed bilaterally on the greater trochanter, center of the patella, and lateral malleolus to determine differences in hip, knee, and ankle joint separation during three phases of the drop jump: Pre-landing, landing, and take-off. At the completion of three jumps, the researcher chooses the best representative jump and analyzes the jump frame by frame to identify the pre-landing, defined as the frame when the athlete's toes just touch the ground after the jump from the box, the landing, defined as the frame in which the athlete has the greatest amount of knee flexion, and the take-off, defined as the frame in which there is initial upward movement to initiate the vertical jump[64]. For each of the three identified frames listed previously, the researcher uses a proprietary software (Valgus Digitizer, Sportsmetrics™ Software for Analysis of Jumping Mechanics, Cincinnati, OH) to digitize the marker points; from the digitized points the software computes absolute difference between right and left hips and normalized difference between right and left knees (knee separation distance/hip separation difference) and ankles (ankle separation distance/hip separation difference)[64]. Less than 60% normalized knee joint separation is representative of abnormal frontal plan knee valgus alignment[64].

Three studies[64,66,67] have evaluated sex differences in the DJST with one documenting no difference between females and male in normalized knee separation distance at landing (51% ± 19% *vs* 51% ± 15%; P > 0.05) and take-off (50% ± 18% *vs* 53% ± 15%; P > 0.05); however, females demonstrated higher normalized knee separation distance than males during the pre-landing phase (63% ± 14% *vs* 59% ± 11%; P < 0.0001)[64]. Barber-Westin *et al*[66] also demonstrated no differences in normalized knee separation distance between sexes across various age groups from 9-17 years of age. In another study of a similar population, females had significantly lower knee-hip ratio (0.45 *vs* 0.63; P = 0.003) (standard deviations were not reported)[67].

In the inaugural study[64] using the DJST to analyze knee joint separation as a means for defining dynamic knee valgus the authors reported the tool is reliable as demonstrated in the following. On a subset of 17 participants who underwent a second DJST 7 wk after the first screening hip joint separation reliability was assessed to provide support for the normalized differences. The authors also presented a subset of another 10 participants in which 2 of the 3 trials were

Table 3 Landing Error Scoring System scoring criteria

LESS item	Operational definition of error
Knee flexion: Initial contact	Knee is flexed less than 30° at initial contact
Hip flexion: Initial contact	Thigh is in line with the trunk at initial contact
Trunk flexion: Initial contact	Trunk is vertical or extended on the hips at initial contact
Ankle plantar flexion: Initial contact	Foot lands heel to toe or with flat foot at initial contact
Medial knee position: Initial contact	Center of patella is medial to midfoot at initial contact
Lateral trunk flexion: Initial contact	Midline of trunk flexed to left/right side body at initial contact
Stance width: Wide	Feet positioned > shoulder width apart at initial contact
Stance width: Narrow	Feet positioned < shoulder width apart at initial contact
Foot position: External rotation	Foot is internally rotated more than 30° between initial contact and maximum knee flexion
Foot position: Internal rotation	Foot is externally rotated more than 30° between initial contact and maximum knee flexion
Symmetric initial foot contact	One foot lands before other or one foot lands heel to toe and other lands toe to heel
Knee flexion displacement	Knee flexes less than 45° between initial contact and max knee flexion
Hip flexion displacement	Thigh does not flex more on trunk between initial contact and maximum knee flexion
Trunk flexion displacement	Trunk does not flex more between initial contact and maximum knee flexion
Medial knee displacement	At maximum medial knee position, the center of patella is medial to midfoot
Joint displacement	Soft: Participant demonstrates large amount of trunk, hip, and knee displacement Average: Participant has some but not large amount of trunk, hip, and knee displacement Stiff: Participant goes through very little, if any, trunk, hip, or knee displacement
Overall impression	Excellent: Participant displays soft landing with no frontal or transverse plane motion Poor: Participant displays large frontal or transverse plane motion, or participant displays stiff landing with some frontal or transverse plane motion Average: All other landings

Flaws 1-15 scored as present: 1 and absent = 0; Flaw 16 scored as soft: 0, average = 1, stiff = 2; Flaw 17 scored as excellent: 0, average = 1, poor = 2. LESS: Landing Error Scoring System.

tested for reliability of absolute separation of the hip, knee, and ankle. The ICCs for hip joint separation were reported as very high at pre-landing (0.96), landing (0.94), and take-off (0.94). The ICCs for absolute separation of the hip, knee, and ankle were reported as all being ≥ 0.90.

Several studies have been published evaluating the effects of neuromuscular training program on the DJST; however, all studies have arisen from the same research group. Further, the validity of such a measurement (knee joint separation) to indicate dynamic knee valgus has never been established. In response to the validity of the DJST, Dr. Noyes and Ms. Barber-Westin state in a Letter to the Editor[68] that "our investigations show the dramatic differences (in landing appearance) between knees with ≤ 60% and those with > 60% normalized knee separation distance". While this does not actually demonstrate that the DJST is a valid measure, there are documented improvements in knee joint separation following neuromuscular training programs in a variety of different athletes[69-71].

Thirty-four female high school volleyball players took part in a 6 wk sport specific neuromuscular training program, which resulted in significant increases in absolute knee separation (21.1 ± 8.2 cm *vs* 25.9 ± 5.2 cm; P = 0.002) and mean normalized knee separation distance (56.3% ± 19.1% *vs* 63.3% ± 12.7%; P = 0.04)[69]. Sixty-two female high school soccer player participated in a 6 wk sport specific neuromuscular training program and had post training increased ankle (27.3 ± 6.3 cm *vs* 34.6 ± 6.0 cm; P < 0.0001) and knee (14.6 ± 3.6 cm *vs* 23.1 ± 24.7 cm; P < 0.0001) absolute separation distance and normalized knee separation distance (35.9% ± 7.4% *vs* 54.2% ± 13.7%; P < 0.0001) when completing the DJST[71]. Fifty-seven female high school basketball players demonstrated increased absolute knee separation (18.5 ± 7.4 cm *vs* 31.8 ± 10.4 cm; P < 0.0001) and mean normalized knee separation distance (44.9% ± 17.2% *vs* 74.2 %± 18.8%; P < 0.0001) following 6 wk of neuromuscular training[70]. Based on the previous suggestion that less than 60% normalized knee separation distance indicating dynamic knee valgus[64]; these findings suggest that a more neutral knee alignment was achieved at landing following the sport specific neuromuscular training programs in female high school volleyball, soccer, and basketball athletes. Additionally, improvements in landing alignment were maintained at 12 mo after a 6 wk neuromuscular training program in approximately 70% of female volleyball players[72]. It is important to note that although the results of the aforementioned studies suggest that landing alignment may be altered following a specific training program; there remains a lack of literature on the validity of the DJST and to date this screening tool has not be used to predict injury risk.

LESS

The LESS is similar to the DJST in the test procedures with the exception that participant's jump landing is video recorded from both the frontal and sagittal planes. In addition, when performing the drop jump landing for the LESS, participants jump from a 30-cm height jump to land on the floor at a distance that is 50% of their height away from the box and then immediately perform a maximal vertical jump. In the LESS, which

Table 4 Landing Error Scoring System scoring criteria real-time

LESS RT item	Operational definition	View	Jump number
Stance width	Participant lands with very wide or very narrow stance (+1)	Front	1
Maximum foot-rotation position	Participants feet moderately externally or internally rotated at any point during the landing (+1)	Front	1
Initial foot-contact symmetry	One foot lands before the other or 1 foot lands heel-to-toe and other foot lands toe-to-heel (+1)	Front	1
Maximum knee-valgus angle	Participant moves into a small amount of knee valgus (+1); Participant moves into a large amount of knee valgus (+2)	Front	2
Amount of lateral trunk flexion	Participant leans to left or right so trunk is not vertical in the frontal plan (+1)	Front	2
Initial landing of feet	Participant lands heel to toe or with flat foot (+1)	Side	3
Amount of knee-flexion displacement	Participant goes through small (+2) or average (+1) amount of knee flexion displacement	Side	3
Amount of trunk-flexion displacement	Participant goes through small (+2) or average (+1) amount of trunk flexion displacement	Side	4
Total joint displacement in sagittal plane	Participant goes through large displacement of trunk and knees, score soft (0); Participant goes through average displacement of trunk and knees, score average (+1); Participant goes through minimal displacement of trunk and knees, score stiff (+2)	Side	All
Overall impression	Participant displays soft landing and no frontal plane motion at knee, score excellent (0); Participant displays stiff landing and large frontal plane motion at knee, score poor (+2); All other landings score average (+1)		

LESS: Landing Error Scoring System.

Table 5 i-Landing Error Scoring System criteria

Good movement pattern	Poor movement pattern
Lands with no knee valgus at initial foot contact	Lands with moderate to large knee valgus position at initial foot contact
Lands with no knee valgus displacement from initial contact to maximum knee flexion	Lands with moderate to large knee valgus displacement from initial contact to maximum knee flexion
Lands with > 30° of knee flexion	Lands with < 30° of knee flexion
Undergoes > 30° of knee flexion	Undergoes < 30° of knee flexion from initial contact to full knee flexion
Minimal to no sound upon landing	Loud sound upon landing

was first described in the literature approximately 6 years ago[73], participants are scored offline *via* a 17 item clinical tool evaluating "landing error" (Table 3) to identify movement patterns that lead to increased ACL injury risk. Newer studies demonstrate the use of real time scoring of four jumps using a modified version of the LESS (LESS-RT) with the scorer evaluating 10 errors during 4 participant jumps (Table 4)[74] and real time scoring using a single jump and the iLESS scoring (Table 5)[75].

The LESS demonstrated good to excellent reliability and was validated against the gold standard of three dimensional kinematic and kinetic analysis in a large study involving approximately 2700 military academy attendees[73]. Intra- (ICC = 0.91) and inter-rater (ICC = 0.84) reliability were established using a random subset of 50 from the initial study; concurrent validity was established by demonstrating that those participants with low LESS scores demonstrated less knee and hip flexion angle, increased knee valgus and hip adduction angle, increased internal knee and hip internal rotation moment, and anterior tibial shear force[73]. The importance of this work is that the authors demonstrated that a clinical movement screen can be used to identify landing errors in multiple planes. Further work has established that the LESS can be used by both novice and expert LESS raters with excellent reliability (overall score: ICC = 0.84; kappa statistics for individual items/landing errors ranged from 80%-100% agreement); however, the validity of the LESS (compared to 3 dimensional motional analysis) is dependent on the item/error being assessed based on Phi-correlation-coefficient analysis leading the authors to suggest that items/errors not valid should be reduced or eliminated from the LESS scoring criteria[76]. To enhance the utility of the LESS, the LESS-RT was developed and the reliability of the composite score (total of 10 errors) was assessed as being good both for interrater reliability (ICC = 0.81)[74]. To create a more efficient clinician screening tool, the iLESS was developed and allows for quicker assessment of large groups in a short amount of time, like a pre participation examination, and demonstrated a high level of agreement between novice and expert raters (iLESS: Kappa = 0.692, Agreement = 90%, P = 0.001; LESS: Kappa = 0.600, Agreement = 80%, P = 0.001) and with the LESS (novice: Kappa = 0.583, Agreement = 85%, P = 0.004; expert: Kappa = 0.500, Agreement = 75%, P = 0.01)[75].

Performance of the LESS is influenced by sex[77,78], fatigue[79], and previous ACL reconstruction[79-81]. In a large study of over 200 collegiate athletes, Lam *et al*[77] found that while males and females demonstrate similar overall LESS scores statistically, males performed worse on items 1, 4, 14 and females performed worse on items 5 and 15 and had more overall frontal plane movement and total errors. This study suggested that

Table 6 Technique flaws of the Tuck Jump Assessment

Lower extremity valgus at landing
Thighs do not reach parallel (peak of jump)
Thighs not equal side-to-side (during flight)
Foot placement not shoulder width apart
Foot placement not parallel (front to back)
Foot contact timing not equal
Excessive landing contact noise
Pause between jumps
Technique declines prior to 10 s
Does not land in same footprint (excessive in-flight motion)

males demonstrate more sagittal plane landing errors while females display more frontal plane landing errors. Beutler *et al*[78] reported that females cadets had lower overall LESS scores compared to male counterparts (5.34 ± 1.51 *vs* 4.65 ± 1.69; $P < 0.001$); this study of 2753 participants also completed a factor analysis and determined that there are five groups of related errors: Factor 1: Knee (item 1), decreased hip (item 2), and trunk flexion (item 3) at initial contact; Factor 2: Knee valgus (item 5 and 15) and wide stance at initial contact (item 7); Factor 3: Toe out (item 10) and knee flexion at initial contact (item 1); Factor 4: Heel-to-toe landing (item 4) and asymmetric foot landing pattern (item 11); Factor 5: Reduced sagittal plane flexion during the landing phase (items 12, 13, and 14)[78]. T-tests between male and females suggested that females are significantly more likely to present with Factors 1, 2, and 5 ($P < 0.001$), while males had greater likelihood of Factors 3 and 4 ($P < 0.001$)[78]. Although not directly tested, the authors suggested that perhaps fatigue worsens movement patterns, which was validated by Gokeler *et al*[79] who demonstrated that after a fatigue protocol in participants with anterior cruciate ligament reconstruction (ACLR) and controls (no ACLR) performed worse on LESS total score compared to pre fatigue scores [median 7.0 (IQR: 4.3; 7.8) *vs* 5.0 (IQR: 2.0; 7.0); $P = 0.001$]. This study also assessed frequency of errors and found that post fatigue ACLR had a greater percentage of errors than control in knee flexion at initial contact, extension on the hips, lateral trunk flexion, and asymmetrical foot contact although the article did not state if these were significant differences[79]. Similarly, Kuenze *et al*[80] and Bell *et al*[81] demonstrated that ACLR have significantly lower total LES scores than healthy controls (6.0 ± 3.6 *vs* 2.8 ± 2.2; $P = 0.002$ and 6.7 ± 2.1 *vs* 5.6 ± 1.5; $P = 0.04$, respectively).

Recent evidence suggests that the LESS can be modified through training[82-84] and it can also be used to identify those at risk for injury[85,86]. Following completion of a military course designed to improve performance in military tasks, cadets had significant improvement in LESS scores (5.01 ± 1.83 *vs* 4.48 ± 1.97; $P < 0.001$)[81]. Similarly, completion of an 8 wk program including progressive resistance exercise and core stability, power, and agility exercises participants performed better on the LESS compared to those who participated in an program that consisted of progressive resistive upper and lower extremity exercises only (pretest: 3.90 ± 1.02, posttest: 3.03 ± 1.02; $P = 0.02$)[83]. However, length of training appears to impact retention of improved performance on the LESS as participants taking part in 9 mo of training maintained movement pattern changes after 3 mo of no training while those that participated in 3 mo of training did not[84].

A very recent report suggests that LESS scores can be used to predict ACL injury risk[85]; however, this is in contradiction to a slightly older study in which LESS scores were unable to predict ACL injury[86]. Smith *et al*[86] was unable to determine a relationship between ACL injury risk and LESS score in a large study of over 5000 collegiate and high school athletes (OR = 1.04 per unit increase in LESS score; 95%CI: 0.80-1.35). Padua *et al*[85], however, was able to identify through ROC analysis that the optimal cut-point for LESS scoring as a predictor of ACL injury was 5.17 (sensitivity: 86%, specificity: 71%) using a sample of 829 youth elite soccer players. Athletes who sustained ACL injury had higher LESS scores than those that did not (6.24 ± 1.75 *vs* 4.43 ± 1.71; $P < 0.005$) and those athletes who had a LESS score of 5 or more had a 10.7 greater risk ratio than those who scored less than 5[85].

The LESS is a reliable tool that appears to have validity although caution should be taken as there may be some items/errors that are not completely validated. Clinicians should account for sex, fatigue, and previous ACLR as these all have demonstrated effects on LESS performance. Further, various types of training programs may improve LESS performance, which may influence ACL injury rate although more studies are warranted at this point.

TJA

The TJA (Figure 5) is a clinical test developed to identify lower extremity landing technique flaws during a plyometric activity[87,88]. The TJA is a quick (10 s) assessment of repetitive tuck jump performance, requiring a high level of effort, which may result in fatigue. The TJA is video recorded in the sagittal and frontal plane and is scored from the recording allowing assessment in slow motion and repeated viewings. There are 10 technique flaws (Table 6) scored as either present or absent during the TJA[87,88].

The benefits of the TJA are that it is a quick, inexpensive, and easy to administer. Two off-the-shelf video camera, tripods, and marking tape are all that is required to complete this test. The cameras must allow full visualization of the trunk and lower extremities with jumping and landing, so this test can be completed with minimal space requirements (8′ x 8′). The TJA takes no more than 2 min to administer, and no more than 10 min to score, making this a viable option for many.

There is limited literature published on the TJA (the 10 s test). A PubMed search using the search terms

Starting point of tuck jump assessment | In flight of tuck jump assessment | Highest point of tuck jump assessment

Figure 5 Images of the Tuck Jump Assessment.

("tuck jump assessment" OR "tuck jump") yielded only 7 results that included the TJA. Despite the lack of evidence, this assessment is widely used clinically based on anecdotal information from PTs, ATs, and performance specialists.

There are 3 studies assessing the reliability of the TJA. The first assessed a different version of the scoring of the TJA[89]. A continuous 10 cm scale was used for 8 technique flaws and reported an intra-rater reliability correlation of 0.84 (range 0.72 -0.97). The TJA scoring was modified to dichotomize the technique flaws (10 rather than the initial 8) to enhance reliability[87], and is the test used in the 2 more recent TJA reliability articles[90,91]. Two raters (including 1 of the developers of the TJA) initially examined inter- and intra-rater reliability in 10 participants 1 mo apart[90]. Excellent inter-rater reliability was reported with high percentage exact agreement (PEA) between the 2 raters (93%, range 80%-100%) and Kappa of 0.88 indicating good/excellent agreement. Intra-rater reliability was also excellent with PEA 96% and 100% for the 2 raters for male participants and average of 87.2% for female participants. Both of these raters are experts and highly educated in movement science, and one of the raters developed the test. Therefore, these excellent results may not generalize to the variety of clinicians who employ the TJA. We examined inter- and intra-rater reliability in 40 participants using 5 raters of different educational backgrounds and clinical experience (PT and PT students, AT, and strength and conditioning coach)[91]. All raters were given instructions, Myer *et al*[88] that describes the TJA and scoring in detail, as well as a scored, example TJA previously scored and consensus achieved by the researchers. Inter-reliability between the 5 raters was poor (ICC = 0.47; 95%CI: 0.33-0.62). Incidentally, the 3 raters who completed the intra-rater reliability improved the inter-rater reliability on the second scoring 1 wk later (ICC = 0.52; 95%CI: 0.35-0.68 for scoring 1 *vs* ICC = 0.69; 95%CI: 0.55-0.81). This improvement in consistency amongst raters may be due to a learned effect with the scoring criteria. Intra-rater ICC (95%CI) was varied for the 3 raters, ranging from 0.44 (0.22-0.68) to 0.72 (0.55-0.84). Surprisingly, the most consistent rater was a 1st year PT student with very little experience in movement analysis. The difference in reliability between these 2 studies highlights the need for more research on TJA for consistent use clinically.

The validity of the TJA has not been formally assessed. Again, the face validity is unquestioned as the developers are movement specialists and have an extensive body of literature on lower extremity biomechanics published from the lab[88,92-94]. Furthermore, Myer *et al*[88] presented a categorization of the 10 TJA technique flaws into five different modifiable risk factors: Ligament dominance, quadriceps dominance, leg dominance or residual injury deficits, trunk dominance ("core" dysfunction), and technique perfection (Table 7). Biomechanical research provided some support for these risk factor categorizations[94], but this has not been assessed clinically or statistically. The responsiveness was also recommended that anyone with 6 or more flaws should be targeted for preventive intervention[88], but no data were presented to justify that recommendation.

The TJA has not been compared with other clinical jumping assessments, but there may be some advantages of the TJA compared with the DJST, which requires a participant to jump off a 30.48 cm box, land, and immediately perform a maximal vertical jump[95]. Because this screening tool involves the use of markers it has a slightly more involved set up. The TJA is also advantageous over the LESS as the scoring for the LESS is more involved as a result of evaluating 17 landing technique errors (present or not) on "a range of readily observable items of human movement"[73]. The TJA is a 10 s test *vs* the 1-2 jumps for other tests and may potentially allow measurement of performance endurance, and fatigue[87]. Similar validation with the TJA is required to ensure the validity of the assessment. The TJA, unlike the other two tests, starts and stops from ground level instead of jumping from a box; this

Table 7 Categorization of 10 technique flaws from the Tuck Jump Assessment into modifiable risk factors

Modifiable risk factor	Description	Technique flaws
Ligament dominance	"Imbalance between the neuromuscular and ligamentous control of the dynamic knee stability"	Lower extremity valgus at landing Foot placement not shoulder width apart
Quadriceps dominance	"Imbalance between knee extensor and flexor strength, recruitment, and coordination"	Excessive landing contact noise
Leg dominance or residual injury deficits	"Imbalance between the 2 lower extremities in strength, coordination, and control"	Thighs not equal side-to-side (during flight) Foot placement not parallel (front to back) Foot contact timing not equal
Trunk dominance/core dysfunction	"Imbalance between the inertial demands of the trunk and core control and coordination to resist it"	Thighs do not reach parallel (peak of jump) Pause between jumps Does not land in same footprint (excessive in-flight motion)
Technique perfection	Not defined	Technique declines prior to 10 s

better represents techniques encountered in normal jumping activities.

None of these jumping assessments have been investigated as an injury prediction tool. All of these assessments were designed to better understand ACL injury, and it is well known that ACL injury are multifactorial, and the mechanism of non-contact ACL injury is multiplanar[73,95], the inclusion of these clinically jumping assessments as a sole predictor for ACL injury is not recommended. Despite the minimal published literature on the TJA, one recommendation can be offered. For the most consistent results, a single clinician should score the TJA if using this to assess progress with an intervention. Further research on the validity is needed to advocate the further use of the TJA clinically.

CONCLUSION

This editorial focused on clinical movement screening tests as they have gained a lot of popularity in the clinical setting as a tool to predict injury and guide injury prevention programs/training. However, clinicians should be aware that various factors like sex differences, previous injury history, and sport participation can influence the accuracy of these screening tests. The validity of the FMS has been questioned and conflicting findings on injury prediction make recommendations for use difficult at this time. The SEBT/YBT appear to have some potential for injury prediction when assessing anterior reach asymmetry, but the CS is a little less clear as there are varying cut-points being identified for injury risk prediction. Additionally, the validity of the SEBT/YBT has yet to be established. It is of the authors opinion that, while both the SEBT and YBT are reliable tools, the YBT is easier to use from a clinician standpoint. The DJST, while proven to detect normalized knee separation differences following neuromuscular training, has yet to be validated or established as a tool to predict injury risk. The LESS appears to have recent potential as an injury predictor; however, results between the only two studies published conflict on this. Additionally, one study has suggested that the LESS may need to have irrelevant items/errors removed to improve validity. Finally, the TJA appeared to be reliable from early studies; however, a newer study suggests that it may not be very reliable and scoring by a single clinician leads to more consistency. Additionally, this tool has yet to be validated or proven as an injury risk predictor.

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EDITORIAL

Understanding the pathogenesis of hip fracture in the elderly, osteoporotic theory is not reflected in the outcome of prevention programmes

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Abstract

Hip fractures are an acute and worsening public health problem. They mainly affect elderly people, a population group that is highly vulnerable to disease and accidents, and to falls in particular. Although it has been suggested that osteoporosis is the cause of hip fractures, they mainly occur after a fall has been suffered. The underlying causes of a fall are not related to osteoporosis, although pharmaceutical companies have coined the term "osteoporotic fracture" for hip fractures in the elderly. Drug treatments for osteoporosis have not diminished the frequency of these injuries, nor have they prevented the occurrence of a subsequent fracture. Since pharmaceutical interests require osteoporosis to be considered a disease, rather than a normal condition of senescence, they go further by assuming that treatment for osteoporosis is essential, and that this policy will diminish the incidence of hip fractures. On the other hand, the origin and treatment of conditions that may be conducive to provoking falls are very difficult to elucidate. In this paper, we consider some of the medical and social problems that arise in this area, as well as conflicts of interest regarding the aetiopathogenesis and prevention of hip fracture, and propose a new paradigm for the prevention of falls.

Key words: Hip fracture; Osteoporosis; Overtreatment; Social medicine; Political economy; Political actions; Conflict of interest; Genome; Transcriptome; Metabolome

Core tip: This paper rejects the role of osteoporosis in the pathogenesis of hip fracture and proposes medically-based political action to support new omics technologies to detect the risk of falls by elderly people, by detracting resources from those currently employed in the treatment of osteoporosis.

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INTRODUCTION

In developed countries, hip fracture is a major public health problem. Increased life expectancy, in conjunction with social changes, has made many elderly persons vulnerable to loneliness and to disability. This population group tends to suffer more frequently from hip fracture because they have a higher propensity to falls, as a result of sensorial and neurological deterioration, together with muscular atrophy. Any elderly person, irrespective of concurrent osteoporosis, may suffer a hip fracture because, apart from the unusual case of pathological fracture, a traumatism is a necessary cause[1]. In other words, in the absence of a fall, hip fracture is very unlikely to occur.

Nevertheless, world-wide programmes to address the question have not been undertaken in accordance with this pathogenic outlook. On the one hand, new and more expensive drugs are continuously being marketed for the treatment of osteoporosis, holding this disease primarily responsible for the occurrence of hip fracture, although such drugs have never been shown to diminish its prevalence or to avoid secondary effects[2]. On the other hand, financial support for these treatments is becoming even more restricted as national health services are forced to cut budgets. Thus, expensive pharmacologic treatment for osteoporosis adds an extra burden to the cost of providing for the needs of elderly patients. The treatment is purported to reduce the incidence of hip fracture, but the practical outcome is a significant reduction in the options open to the public welfare system, with particular regard to pensions, and in consequence many elderly people lack the means to cope with this situation.

Therefore the problem of hip fracture is twofold: Medical and social. Any approach to this pathology must take into account both aspects, if health policies for hip fracture prevention are to be successful.

THE MEDICAL PROBLEM

Falls are known to be the main cause of hip fracture. However, this pathology is commonly held to be closely related to osteoporosis. The pharmaceutics industry has coined the term "osteoporotic fracture" for any fracture suffered by an elderly person. Although all elderly people do indeed present osteoporosis, among other aspects of their health status, they may also be affected by heart disease, stroke or ocular or inner-ear balance problems, any one of which may provoke a fall. However, the fracture is never called an "ophthalmic fracture" or a "labyrinth fracture".

Since osteoporosis alone never provokes a fall, and as a fall is the main antecedent of a hip fracture, there must be some mismatch in the assumption of causality between osteoporosis and hip fracture, *i.e.*, in the pathogenesis of this condition. Osteoporosis only helps to fracture a bone with less energy than non-osteoporotic bone. It has been established that although all elderly people present osteoporosis, only some will suffer a fall, and that less than half of those having a fall will suffer any injury as a result of it[3]. Moreover of the persons aged 65 years or older who do suffer a fall, over half will experience a repeat of this event within a year[4]. Although these persons may or may not suffer a hip fracture, pharmaceutical companies cite this circumstance to argue that persons who have had an "osteoporotic fracture" need treatment to prevent the occurrence of a second one. It has been claimed that in order to prevent hip fractures, the supposed bone metabolism disorder that diminishes "bone strength" should be treated. Nevertheless, the available evidence does not show that, as discussed below.

The oral intake of vitamin D, with or without calcium, is the classical treatment for osteoporosis. Nonetheless, low plasma 25-hydroxy vitamin D concentration is associated with high arterial blood pressure and the risk of hypertension[5], and therefore a constant therapy of vitamin D, either alone or combined with calcium, for the prevention and treatment of osteoporosis, in the absence of explicit risk factors for vitamin D deficiency, appears to be inappropriate[6,7]. Indeed, this therapy may provoke a significant rise in gastrointestinal symptoms and renal diseases[6]. Yet despite the dangers, nearly half of all over-50s continue to use these supplements[8]. The effect of vitamin D on the mortality of the elderly is in fact very odd: Whereas vitamin D3 seems to decrease mortality, vitamin D2, alfacalcidol and calcitriol apparently have no beneficial effects at all[6], and may even provoke hypercalcaemia; moreover, if vitamin D3 is administered together with calcium supplementation, the risk of nephrolithiasis is increased[7]. However, the current use of vitamin D by elderly people as a strategy for the prevention of hip fracture could be promoted just for its effects on muscular atrophy. This would reinforce the hypothesis that hip fracture is provoked by a fall, not by osteoporosis.

Mineralisation deficit has also been proposed as a cause of "bone weakness" making elderly persons liable to suffer an "osteoporotic" hip fracture. But according to recent studies, the problem of mineralisation in elderly people is not one of a regular decrease of calcium in the bone, but rather the irregular distribution of its mineralisation. Tissue mineral density is significantly higher in the periosteal, and decreases from there to the endostium; it diminishes from the distal to the proximal part of the femur neck, and thus varies in a radial fashion. In addition, tissue variations in the axial direction of the femoral neck are responsible for important alterations in bone elasticity. Therefore, this spatial heterogeneity of elastic coefficients of bone tissue has consequences for bone as an organ[9,10]. In a similar fashion, mineral crystals at the external cortical bone surfaces of the femoral neck of patients with a fractured hip are larger than in a non-fracture control group. Moreover, the mineral content is higher, with cortical porosity values being almost 35% higher than in control groups, while the osteocyte lacunar number density is significantly lower than in controls[11]. Consequently, the cortical bone of the superolateral femoral neck of hip fracture patients presents distinct signs of fragility at various levels of its structure[12]. These findings could be very important to understanding the pathogenesis of bone weakness in hip fractures. Hence, merely providing "remineralising" drugs to prevent the occurrence of hip fracture appears too simple a notion. Recent research findings have further reinforced the hypothesis that hypermineralisation and the heterogeneity of mineralisation patterns are at the root of bone fragility[9-12].

An increased mineral content of bone tissue, in addition to heightened porosity, has also been observed in femur bone obtained from autopsies[13], with the consequent deleterious effects on bone strength and the risk of fracture.

The calcium-phosphorus ratio does not vary between hypermineralised osteocyte lacunae and bone matrix, according to studies of osteoporotic patients and an osteoarthritic control group. The role of hypermineralised osteocyte lacunae in the biomechanical properties of bone is not totally clear, but investigating the relation between hypermineralisation and femoral neck fracture susceptibility would constitute a very interesting line of research to obtain a better knowledge of the bone stiffness-flexibility relation. Previous studies have found that bone fragility may be greatly increased in the presence of bone tissue heterogeneity in osteons and interstitial tissue[12], and other researchers have reported that the degree of bone tissue mineralisation is significantly lower in the osteons than in the interstitial tissue both in hip fracture patients and in controls, whereas the presence of osteons and interstitial tissue is significantly greater in hip fracture patients. These data further support the view that bone fragility may be related to a higher degree of tissue mineralisation[14].

We performed similar studies, but retrieving the bone samples from the base of the femoral neck, as in osteoarthritis the femoral head becomes very dense, and obtaining the samples from this area might provoke a bias, in comparison with samples from osteoporosis patients. We determined microcrystalline salt standards in order to quantify Ca and P, in accordance with the methods reported in previous publications by our group[15]. All results were calculated as the weight fraction percentage of Ca and P[16]. Cancellous bone in hip osteoarthritis was found to be stoichiometrically similar to normal bone; that is to say, it is characterised by a Ca/P molar ratio corresponding to hydroxyapatite. However, the cancellous bone in hip fracture patients had an increased Ca/P ratio, associated with higher concentrations of Ca and P. We believe this further refutes the idea that calcium intake should be increased or drugs administered to "improve mineralisation" in osteoporotic patients and thus prevent hip fracture (unpublished data). The determination of Ca and P fractions in bone mineral density (BMD) in order to enhance fracture risk assessment and thus enable more targeted therapies to be devised has also been recommended[17].

Other therapies intended to diminish the risk of hip fracture, such as the combination of anabolic agents with bisphosphonates, have had little success. Similarly, the combination of teriparatide and denosumab, although increasing the bone matrix density more than is achieved by either agent alone[18], not only does not reduce the risk of fracture but may also produce long-term collateral effects. These new therapies, targeted at inhibiting bone resorption and enhancing bone formation, through a better understanding of the signalling network for osteoblast-osteoclast coupling, will allow novel therapeutic targets to be established for osteoporosis treatment but they have nothing to do with decreasing the risk of hip fracture. Denosumab, a monoclonal antibody for the receptor activator of the NF-κB ligand, a key osteoclast cytokine; odanacatib, a specific inhibitor of the osteoclast protease cathepsin K; and antibodies against the proteins sclerostin and dickkopf-1, two endogenous inhibitors of bone formation, have all achieved promising results in the treatment of osteoporosis[19].

Therefore, if osteoporosis were the cause of hip fracture, then by treating osteoporosis many fractures could be prevented. However, as the real causal framework is different, the following questions (and answers) arise. What actually provokes a fracture? In many cases, a fall and what provokes a fall? In many cases, a sensory deficit and which sensory deficits are capable of provoking a fall? Apparently, ophthalmic and/or auditory disorders, brain disease or reduced mobility. In consequence, taking action to prevent falls caused by these circumstances will reduce the prevalence of hip fracture. Unfortunately, comparison between races (Caucasian *vs* Asian, and particularly to black race) is very difficult as social situation are different.

THE SOCIAL PROBLEM

Funding

Undoubtedly, if pharmacological treatment for osteoporosis were the solution for "osteoporotic" hip fractures, financial support for this purpose would be needed. Funding would have to be obtained either directly, from the patient, or indirectly, *via* a public welfare system. Since the end of World War 2, European welfare systems, based on principles of solidarity, have been the linchpins of funding for disease prevention and treatment programmes. However, following the onset of the economic crisis in 2007, governments have declared that such systems are no longer sustainable. National health service budgets have been slashed throughout Europe[20], but in many countries pharmaceutical expenses are either still rising or are falling at a slower rate than other items in health system budgets, thus forming a recurrent financial problem that presents a major challenge to society.

In Europe, national health services spent typically accounts for 6%-12% of Gross Domestic Product (GDP), but elsewhere the situation may be very different. Thus, in the United States, where a more market-oriented system exists, health spending represents nearly 18% of GDP. Nevertheless, a large sector of the population remains without access to a good quality health service. Private medical insurance can be cripplingly expensive, and many are forced to do without in order to meet day-to-day living costs. The Health Alliance International of the Washington University School of Public Health has reported that for this reason millions of persons in the first world are condemned to suffer avoidable disease and early death[21].

The austerity policies currently being applied throughout Europe slow economic growth and hamper the repayment of external debt[22-24]. Paul Krugman, the Nobel Prize-winning economist, has advocated raising government budgets for public welfare policies, including health programmes[25,26]. Similar conclusions were drawn by Greek authors in a recent paper published in the *Lancet*[27].

National policies to prevent hip fracture need generous budgets, but since spending cannot rise indefinitely, national budgets for healthcare policies must be focused on efficiency and effectiveness. Thus, current spending on ineffective medicaments should be readdressed toward effective medical actions, and as the medical treatment of osteoporosis does not reduce the prevalence of hip fracture[2,8,28,29], the national health services budgets for such treatments should be reassigned toward social support, particularly fall prevention. The question remains: Will national governments do so?

The power of pharmaceutical companies

There is much current debate concerning the real need for medicaments. An increasing number of doctors are convinced that a significant proportion of the drugs currently prescribed are ineffectual if not actually harmful[28-44]. Obviously, many drugs are necessary and valuable, but pharmaceutical and medical device companies often trial their products among the most favourable population and comparison groups in order to obtain the most positive outcomes for their interests. Company staff controls the data and perform the analyses in-house, while academic researchers are often paid to be listed among the authors when in fact they have contributed little and cannot vouch for the data presented; although difficultly, current rules, and regulations try to avoid that. Many "opinion leaders" work for pharmaceutical companies as advisers, and most doctors on the committees of scientific societies have links to companies that are an important source of funds to these societies[28]. In many cases, too, trials with negative results are suppressed and remain unpublished[29-31]. In the nineteenth century, Quetelet[30] observed, "society prepares the crime and the guilty person is only the instrument by which it is executed", and this proposition is still applicable today.

Drug companies are very powerful and have often been accused of making illicit payments to individuals or institutions to further their ends. In addition, many have been convicted of marketing harmful - often fatal - drugs, of committing fraud, of manipulating prices and of concealing evidence[31]. The fines levied against drug companies for these offences are insignificant in comparison to the enormous profits obtained, and are often regarded as merely the cost of doing business[31]. In 2012, a major United States pharmaceutical company agreed to pay a fine of $60.2 million in order to forestall an investigation into the corruption of foreign doctors, hospital managers and pharmaceutical controllers in Europe and Asia[32].

Both in the United States and elsewhere, the large pharmaceutical concerns head the ranking of the most unlawful companies[31,33]. In the United States, the drug market is regulated by politicians, who have come to be a prime target for industry lobbying[31]. At one point, indeed, the United States Secretary of Defense was at the same time the Chief Executive Officer of an important pharmaceutical company, while the budget director of the White House later became Vice-President of a top drug company, and the President himself was a member of the board of this company before coming into power[28].

The same conflict of interest issue has occurred in the United Kingdom. Thus, in 2005 the House of Commons Health Committee highlighted the enormous and uncontrolled power of the pharmaceutical industry, and accused it of exerting pressure on doctors, Non-governmental organizations, patients' associations, journalists and politicians[34-37]. Nevertheless, after receiving this report, the British Government did nothing to change the situation - an outcome influenced by the fact that the pharmaceutical industry, after tourism and finance, is the most profitable business activity in the country[31,35].

Several books have analysed this problem in detail, including a recent very well documented one by the director of the Nordic Cochrane Centre[31], two by past editors of the *New England Journal of Medicine*[28,38] and one by an editor of the *British Medical Journal*[39]. Other publications have reported on abuses in specific medical fields[40-42] and on the scourge of overdiagnosis[29,43,44].

Are osteoporosis patients victims of this conflict of interests?

The treatment of osteoporosis is also affected by the above-described conflict of interests. In 2005, a major drug company agreed to pay $36 million to settle criminal and civil charges related to the illegal marketing of raloxifene, a drug used in the treatment of osteoporosis. The company had claimed this medicament prevented breast cancer and cardiovascular diseases, but failed to reveal that it also increased the risk of ovary cancer[31].

The problem in this context begins with the very definition of osteoporosis. The pharmaceutical industry, among others, sponsors the definition of diseases[45,46]. Although osteoporosis is defined as a metabolic disorder characterised by decreased bone mass and deteriorated bone structure, resulting in an increased susceptibility to fractures[47], osteoporosis - the visual image of osteopaenia - is actually a normal skeletal situation among elderly people. The World Health Organization (WHO) definition of osteoporosis is based on bone density data presented by young women[48], which has nothing to do with the situation of elderly persons, among whom bone deterioration is just a part of body decline in general. No objective reason was presented by the WHO group on osteoporosis when it was decided that anyone with a BMD that lies 2.5 standard deviations or more below the average value for young healthy women would be considered as having osteoporosis[48]. However, so far, no an alternative standard has been published.

On the basis of the WHO definition, densitometry is considered by patients' associations to be the gold standard for the diagnosis of osteoporosis. However, according to technological evaluation agencies, the truth is quite the opposite[31]. Both the defining body and many patients' associations are funded by pharmaceutical companies[31], which have an evident interest in ensuring that all persons presenting osteoporosis, under the WHO densitometry definition, should receive pharmaceutical treatment[48]. It has been shown that all post-menopausal women will present osteoporosis. In consequence, according to the drug companies' approach, from a given age, at least half of the entire population should be pharmacologically treated for this disease. In fact, the evidence base has been systematically distorted, and evidence-based medicine and guidelines have been hijacked by pharmaceutical companies[49,50].

Health technology agencies have published data obtained from five independent evaluations of the predictive performance of bone density measurements. Depending on the threshold values used and the assumed lifetime incidence of hip fracture, these studies have reported predictive values for positive results in BMD tests ranging from 8% to 36%[51]. Similarly, recent systematic reviews have concluded that there is insufficient evidence to inform the choice of which bone turnover marker to use in routine clinical practice to monitor the response to osteoporosis treatment. Consequently, the research priority should be to identify the most promising treatment-test combinations for evaluation in subsequent, methodologically sound, randomised controlled trials (RCTs), in order to determine whether or not bone turnover marker monitoring actually improves treatment management decisions, and ultimately impacts on patient outcomes in terms of reduced incidence of fracture. Given the large number of potential patient population-treatment test combinations, the most promising combinations would initially need to be identified in order to ensure that the RCTs focus on evaluating those strategies[52]. Such projects should also focus on the multifactorial etiology (co-morbidity, type and circumstances of trauma, polypharmacy, previous fractures, hereditary, menopause, *etc.*) of broken bones. International registries are a major step forward to this approach.

BMD studies do not predict hip fracture and long-term pharmacological treatment for osteoporosis does not reduce the incidence of hip fracture cases[53]. Furthermore since the new drug-induced bone formed has not a normal structure, iatrogenic fractures can appear. The majority of women of menopausal age are at low risk of "osteoporotic" fracture in the short-medium term. If BMD testing leads to unnecessary treatment and anxiety (typical effects of disease mongering), it may do more harm than good[45].

Moynihan *et al*[45] suggest that preventive medicine is threatening the viability of publicly funded healthcare systems, and that osteoporosis has been effectively sponsored by the pharmaceutical industry. Too many people who fall and develop a fracture are considered for treatment of osteoporosis[45]. Conversely, systematic reviews of randomised trials have shown that the decline in BMD is attenuated with exercise[54,55], and one such review found that some forms of supervised exercise increase muscle mass and reduce the incidence of falls[56]. Observational studies have shown there is a protective association between regular exercise and hip fracture[57].

The field of osteoporosis is an obscure one, particularly when conflicts of interest arise in addressing the relationship between osteoporosis and hip fracture. There are three main reasons why a patient with osteoporosis or any disease may experience symptomatic improvement: Medicament effect, placebo effect and the natural course of the disease. Most published reports of patient improvement are strongly affected by bias[31]. In the field of orthopaedics, unfounded research claims have been made by companies manufacturing joint implants[58,59]. Apart from medical researchers and physicians, scientific journals also seem to have been affected by dishonest reporting[60]. Osteoporosis associations reject comments on their funding[61], but the fact is that while some osteoporosis associations receive funding from government agencies, lists of commercial sponsors also appear on their websites[28,31,45].

A PROPOSED NEW PARADIGM FOR THE AETIOPATHOGENESIS OF HIP FRACTURE IN THE ELDERLY: THE BASIS OF PREVENTION

Since hip fracture is usually caused by a fall, by identifying the population with a propensity to suffer a fall, *i.e.*, those with a sensory or cognitive problem aggravating the risk of a fall, and then providing proper treatment for such problems, both falls and hip fractures could be prevented.

Each year, approximately 30% of non-institutionalised persons aged over 65 years suffer a fall. Group and home-based exercise programmes and home safety interventions can reduce the risk and hence the rate of falls[54,55]. Multifactorial assessment and public health intervention programmes, on the other hand, reduce the rate of falls but not the risk of falling; certain specific forms of exercise, such as Tai Chi, also reduce the risk of falling. Vitamin D supplementation does not appear to reduce the risk or rate of falls but may be effective in people who have low levels of vitamin D before treatment[56].

Hip protectors probably reduce the risk of hip fractures when provided to older people in nursing care or residential care settings, without increasing the frequency of falls. However, since they are very uncomfortable, patients keep them in the wardrobe. They also may slightly increase the risk of pelvic fractures. Poor acceptance and adherence by older people offered hip protectors is a barrier to their use[62].

Together with these physical actions to prevent falls, some basic lines of scientific research must be undertaken to establish a new paradigm. In this respect, genetic research has been employed to address the question of osteoporosis. It has been reported that two gene variants of key biological proteins can increase the risk of osteoporosis and osteoporotic fracture. The combined effect of these risk alleles on fractures is similar to that of most well-replicated environmental risk factors, and they are present in more than one in five white people, suggesting a potential role in screening[63]. Although the authors of this paper studied the risk of osteoporosis they did not consider the risk of fracture or of falls. Another study, in an *in vivo* analysis of zebrafish, examined the bone regulatory properties of plastin 3 (PLS3), a protein involved in the formation of filamentous actin (F-actin) bundles, and found it to be related to osteogenesis imperfecta type Ⅰ, with a rare variant (rs140121121) in PLS3. The association of this variant with the risk of fracture among elderly heterozygous women indicates that genetic variation in PLS3 is a novel aetiological factor that is involved in common, multi-factorial osteoporosis[64]. The question then arises: How many elderly persons present this complex mechanism, which, according to theory, can account for the risk of hip fracture?

One thing is to alleviate osteoporosis but quite another to imagine that, even if this were achieved, it would prevent or reduce the incidence of hip fracture. New research into "omics" is enhancing our understanding of the pathogenesis of osteoporosis, but this does not mean that a new paradigm for the aetiopathogenesis of hip fractures is being created. Again, in accordance with the real causality framework that has been established, research should be focused, not on osteoporosis, but on preventing falls by vulnerable persons. New findings in the fields of the human genome, transcriptome and metabolomics, if appropriately addressed, would reveal the susceptibility of elderly people to falls and thus open the way to preventing many hip fractures.

Genome

The completion of the Human Genome Project[65], followed by the development of a more manageable understanding of the human genome in the Hap Map Project[66] and the launch of Genome-Wide Association Studies (GWAS)[67], marked a great accomplishment and initiated a burst in scientific discovery of the genetic underpinnings of common diseases. Therefore it is expected that our knowledge of the factors provoking falls will also benefit from genome studies.

GWAS have located most of the very common gene variants in the human genome and have identified over 500 independent strong single nucleotide polymorphism associations. The 1000 Genomes Project[68] and the UK10K Project[69] are population-level sequencing projects that have led to an explosive growth of individual whole genome sequencing (WGS) data.

In the post-genomic era, next-generation sequencing (NGS) technologies have become more accessible in terms of cost, analytic validity and rapidity. Whole-exome sequencing (WES) using NGS has the capacity to determine in a single assay an individual's exomic variation profile, limited to about 85% of the protein coding sequence of an individual, composed of some 20000 genes, 180000 exons, and constituting approximately 1% of the whole genome. A sensitivity of 98.3% for detecting previously identified mutations, as well as benign variants, has been reported by WES[70]. Furthermore, WES allows the phenotype expansion and identification of new candidate disease genes that would have been impossible to diagnose by other targeted testing methods[70]. Proof-of-concept examples of the identification of rare, disease-causing variants are now available for WGS and WES strategies[71-73]. A major indication for their use is the molecular diagnosis of patients with suspected genetic disorders or that of patients with known genetic disorders with substantial genetic heterogeneity involving significant gene complexity. Particular limitations in WES are the gaps in coverage of the exome, the difficulty of finding the causal mutation among the enormous background of individual variability in a small number of samples, and the difficulty interpreting variants. It is in this field of work where new bioinformatic tools are currently of great assistance to researchers. A large database would be of great benefit in producing a profile of elderly people predisposed to suffer falls.

Transcriptome

The transcriptome is the complete set of transcripts in a cell, and their quantity, for a specific developmental stage or physiological condition. Understanding the transcriptome is essential for interpreting the functional elements of the genome and revealing the molecular constituents of cells and tissues, and also for understanding development and disease. The key aims of transcriptomics are: (1) to catalogue all species of transcript, including mRNAs, non-coding RNAs and small RNAs; (2) to determine the transcriptional structure of genes, in terms of their start sites, 5' and 3' ends, splicing patterns and other post-transcriptional modifications; and (3) to quantify the changing expression levels of each transcript during development and under different conditions[74]. The human transcriptome is comprised of over 80000 protein-encoding transcripts and the estimated number of proteins synthesised from these transcripts is in the range of 250000 to 1000000. These transcripts and proteins are encoded by fewer than 20000 genes, suggesting a wide regulation of transcription, at the post-transcriptional and translational levels. RNA sequencing (RNA-seq) technologies have increased our understanding of the mechanisms that give rise to alternative transcripts and translations[75]. Next-generation sequencing technologies are evolving rapidly and it is likely that RNA-seq will become routine for many laboratories in coming years. Sequencers are becoming smaller and more personal and are beginning to equip individual departments and laboratories. Library preparation protocols are also becoming shorter and more efficient. Single molecule sequencing will afford insights into the precise orientation of transcription. Advances in methods to acquire sequences are likely to be accompanied by equally rapid advances in computation and data analysis[76].

The study of transcriptome allows us a deeper understanding of the pathogenesis of various diseases and makes it possible to select biomarkers to facilitate the early detection and therapeutic monitoring of these diseases. Recently published studies have compared healthy bone tissue with that of patients diagnosed with osteosarcoma (OS). Differences in the expression of certain genes were found between these experimental groups. These genes appear to be involved in the development of OS or other cancers, and could be used as biomarkers or as new drug targets[77]. Other studies have shown how multiple transcription factors and multiple signal transduction pathways are coordinated and temporally regulated during endochondral bone formation. Modelling these pathways and the interactions of groups of strain-specific genes will allow us to infer the interactions between transcription factors and signal transduction pathways that coordinate the training of vascular and skeletal tissues[78].

The study of bone transcriptome can enhance our understanding of the pathogenesis of hip fracture, enabling us to select biomarkers and thus facilitate early detection of elderly persons' susceptibility to falling. Nevertheless costs of these projects, and, if possible, therapy for these patients are unknown.

Metabolomics

Metabolomics is an emerging multidisciplinary science that requires cooperation between chemists, biologists and computer scientists. The metabolome refers to the complete inventory of small molecules, non-protein compounds, such as metabolic intermediates (ATP, fatty acids, glucose, cholesterol, hormones and other signalling molecules), and secondary metabolites found in a biological sample[79,80].

The metabolome changes continuously, depending on the activation and interaction of the various metabolic pathways within the cell. It also reflects the phenotype that can be used to interfere with gene function. Although genomics and proteomics can provide important information on the expected function, metabolomics provides an immediate snapshot of all biological functions that reflect current events at an exact moment[81,82]. By measuring the population of biomarkers (metabolites), it may be possible to distinguish the profiles or signatures of healthy individuals from those of persons with specific diseases[83]. Moreover, metabolomics may provide evidence of a metabolic disorder or injury with a high degree of precision and at less cost than by means of genomics, transcriptomics or proteomics. Therefore, it is a very suitable technique for generalised research in life sciences[84,85]. In the last decade of development of spectrometry, metabolic profiling using high-resolution magic-angle-spinning nuclear magnetic resonance (HR-MAS NMR) has made it possible to analyse intact tissue.

This technique has been applied to the study of specific tissue toxicity, to characterise the composition and structure of tissues, and to analyse human samples (such as biopsies, cells or tumours)[86,87]. In recent years, the number of papers published in this field has grown appreciably, and many of these describe the characterisation of the metabolic profile of different types of human tumours, including brain tumours[88,89], breast cancer[90-92], colorectal cancer[93] and prostate cancer[94,95]. The fact that no sample processing takes place provides the added advantage that the tissue can be recovered and analysed histologically a posteriori, thus providing the possibility of establishing direct correlations between the metabolic profiles and the histological[96] or even genomic results[97].

CONCLUSION

Precision medicine (PM) has the potential to produce a fundamental change in how health care is practiced, but it does require health care personnel to understand the complexities present in this field. An important component of PM is the use of an individual's genomic information to offer targeted treatment, tailored to the individual. Whether or not the "omic" technologies eventually provide a practical contribution to our understanding of causality, offering significant advances in the real aetiopathogenesis of hip fracture, in any case, they will not appear to be subject to any conflict of interest, although new industries for "omic" technologies are emerging. If this advance comes to pass, will over-diagnosis cease to be a problem caused by scientific misjudgement or by conflicts of interest[98-100]. The respond will be in the future.

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REVIEW

Elbow ulnar collateral ligament injuries in athletes: Can we improve our outcomes?

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Abstract

Injury to the ulnar collateral ligament (UCL) most commonly occurs in the overhead throwing athlete. Knowledge surrounding UCL injury pathomechanics continues to improve, leading to better preventative treatment strategies and rehabilitation programs. Conservative treatment strategies for partial injuries, improved operative techniques for reconstruction in complete tears, adjunctive treatments, as well as structured sport specific rehabilitation programs including resistive exercises for the entire upper extremity kinetic chain are all important factors in allowing for a return to throwing in competitive environments. In this review, we explore each of these factors and provide recommendations based on the available literature to improve outcomes in UCL injuries in athletes.

Key words: Elbow; Ulnar collateral ligament; Valgus instability; Tommy John surgery; Rehabilitation; Overhead athlete; Improved outcomes

Core tip: While surgical techniques undoubtedly affect the outcome following ulnar collateral ligament (UCL) reconstruction, they do not independently do so. Rather, it is a complex milieu of pre-operative, intra-operative, and post-operative factors that combine to affect the overall outcome following UCL injury. Due to the variability in success rates for treatment of these injuries, careful review of each of these factors is required to ensure outcomes are optimized following treatment. This study serves as a review of these factors, providing recommendations based on available literature to improve outcomes following UCL injuries in athletes in future years.

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INTRODUCTION

Ulnar collateral ligament (UCL) injuries have occurred with an increasing incidence among throwing athletes in recent years[1]. Once considered a career-ending injury, Dr. Jobe's reconstructive technique revolutionized the treatment of these injuries, improving outcomes and return-to-sport following surgical reconstruction[2]. Since that time, attention has focused on optimizing the surgical technique, with several subsequent modifications aimed at improving outcomes and minimizing associated complication rates. While seemingly successful based on summative analyses in recent systematic reviews[3,4], the results are inconsistent, with return to play rates varying from 53%-90%[5-9] and complication rates varying from 3%-25%[10,11]. This disparity in outcomes following surgical reconstruction has prompted further study into the management of UCL injuries beyond advancements in surgical techniques. Consequently, knowledge surrounding UCL injury pathomechanics continues to improve, leading to better preventative treatment strategies and rehabilitation programs[1,12,13]. Additionally, the role of rigorous post-operative rehabilitation programs is a significant contributing factor to successful return-to-sport following surgical reconstruction[14,15].

While surgical techniques undoubtedly affect the outcome following UCL reconstruction, they do not independently do so. Rather, it is a complex milieu of pre-operative, intra-operative, and post-operative factors that combine to affect the overall outcome following UCL injury. Due to the variability in success rates for treatment of these injuries, careful review of each of these factors is required to ensure outcomes are optimized following treatment. This study serves as a review of these factors, providing recommendations based on available literature to improve outcomes following UCL reconstruction in future years (Table 1).

NON-RECONSTRUCTIVE OPTIONS

Throwing athletes who have sustained UCL injuries often require surgical reconstruction in order to return to their preinjury level of activity. There are, however, non-operative and non-reconstructive modalities that may be utilized in certain clinical scenarios permitting earlier return to sport without the morbidity associated with reconstruction.

Non-operative treatment can include rest, non-steroidal anti-inflammatory drugs (NSAIDs), and bracing along with physical therapy. Rettig *et al*[16] described a 2-phase non-operative rehabilitation program. Phase 1, typically 2 to 3 mo in duration, consisted of rest, bracing, NSAIDs and progressive range of motion (ROM) exercises. If pain-free at the end of this phase continued, strengthening and throwing progression programs were started. In some scenarios involving lifting or throwing, bracing was used to prevent elbow hyperextension. With this protocol, they had success in returning 42% of throwing athletes to their pre-injury level of activity at an average of 24.5 wk[16]. Additional non-operative measures include activity modifications, which may include sport cessation or a position change, allowing continued participation without surgical treatment. Beyond these non-operative measures, additional non-reconstructive treatment options include platelet-rich plasma (PRP) treatment or primary repair of the UCL.

Table 1 Key factors for improving outcomes in ulnar collateral ligament injuries at various time points

Time point	Target points for improved outcomes
Pre-op	Patient selection
Intra-op	Do not transpose nerve unless symptoms present preoperatively
	Docking > Jobe (complications)
Post-op	Sport specific rehabilitation
	Isokinetic testing
	Return to throw program
	Daily stretching exercises

PRP use has increased substantially for treatment of various tendon and ligament pathology, however little literature exists on its use specifically in UCL injuries. A recent retrospective review by Dines *et al*[17] examined 44 baseball players treated for partial thickness UCL injuries with PRP. Levels of participation varied from professional (6), collegiate (14) and high-school (24). Though a small cohort, outcomes following treatment with PRP were best in the professional group with 67% returning to play[17]. Only 36% of the collegiate athletes and 17% of the high school athletes had excellent outcome scores based on a modified Conway Scale[17]. Overall these outcomes are worse than UCL reconstruction and should be reserved for specific patient groups. One such group may include athletes who are late in their professional careers and unable to undergo necessary post-operative rehabilitation. Return to pitching following reconstruction requires 12+ mo of post-operative rehabilitation, while return from non-operative treatment with PRP is significantly shorter, based on the ability to progress through an interval-throwing program. Therefore, these older overhead athletes may receive the most benefit from a PRP injection following partial UCL injury[18].

While PRP may have a positive effect on UCL healing, corticosteroids have a negative effect on ligament healing and are not recommended for use following acute ligamentous injuries. Using a rabbit model, Walsh *et al*[19] injected betamethasone into a surgically created UCL defects, reporting negative effects on both biomechanical and histologic properties of the healing ligament. As a result of the deleterious effects on ligamentous healing, corticosteroids are not recommended in the treatment of acute UCL injuries[19].

Primary repair of the UCL, rather than reconstruction, may permit more rapid return to play and improved outcomes in specific patient groups[20,21]. Younger athletes who sustain UCL injuries have a distinct injury pattern from professional athletes that is more amenable to repair, typically confined to either the proximal and/or distal aspect of the UCL rather than a degenerative mid-substance injury attributable to repetitive micro-trauma[20,21]. In 2008, Savoie *et al*[21] reported the outcomes of primary repair of UCL injuries in patients averaging 17.2 years of age, with nearly 5 years of follow-up. Through their work, they identified that the best candidate for this treatment type is one with an acute avulsion injury without signs of previous degenerative injury and no noted concomitant injuries. Their described technique includes a diagnostic arthroscopy for confirmation of pathology, followed by a muscle-splitting approach[22] with capsular reflection along the anterior edge of the ligament permitting evaluation of intra-articular damage. Anatomic repair is performed using bone tunnels or a double loaded anchor, securing the injured ligament proximally at the base of the medial epicondyle or distally at the center of the sublime tubercle[21].

Post-operative rehabilitation includes splinting followed by full time hinged ROM brace wear and an expedited standard rehabilitation protocol[15]. Progressive return to play was permitted in an ROM brace at 6-8 wk post-operatively with progression out of the brace at 12 wk with return to full activities upon graduation from the return to play program at 16 to 24 wk post-operatively[21]. Results for primary repair in this specific patient cohort were excellent with 93% (56 of 60) patients returning to sporting activities within 6 mo. This included 40 patients with proximal UCL repairs, 11 with distal UCL repairs and 9 with combined proximal and distal UCL repairs[21].

The results of Savoie *et al*[21] are similar to results of primary repair reported by Richard *et al*[20] in a collegiate patient population with an average age of 27 who sustained combined acute UCL and flexor-pronator avulsion from the humeral origin. Of the 11 patients who underwent primary repair through bone tunnel fixation, 9 returned to collegiate athletics between 4 and 6 mo post-operatively[20]. Though this study is limited by short, 16-mo follow-up and a wider variety of sporting activities with fewer overhead athletes, it illustrates a patient population that may benefit from primary UCL repair.

Both of these studies' outcomes differ from earlier results from Conway *et al*[10] who reported outcomes for patients treated with either UCL repair or reconstruction. In their study of throwing athletes only 50% of patients undergoing a direct repair returned to their previous level of sport compared to 68% of those undergoing a reconstruction[10]. Even worse outcomes were obtained in major-league baseball players undergoing primary repair with only 2 of the 7 being able to return to sport[10].

In short, UCL repair may be a viable surgical option in young athletes with acute injuries, resulting in excellent outcomes and permitting earlier return to play than following UCL reconstruction. This procedure, however, should be limited to young athletes without degenerative UCL injuries as is often encountered in collegiate and professional baseball players.

RECONSTRUCTIVE OPTIONS

Ulnar collateral ligament reconstruction has been effective in returning athletes to sport in approximately 80% of cases[3]. However, the results differ widely depending on the surgical series, with highly variable return-to-play rates (as low as 53%) and complication rates (as high as 25%), often related to the specific reconstructive techniques. In addition, studies have identified significantly inferior functional outcomes among those who re-tear their UCL and require revision UCL reconstruction, with a return to play rate ranging from 33%-78%[23-25]. Due to the variability in achieving a successful outcome following UCL reconstruction, and the ramifications of re-injury and revision surgery, careful review of surgical techniques is necessary to ensure that appropriate surgical steps are taken to optimize outcomes and limit complication and re-rupture rates.

Surgical techniques

Surgical reconstruction of the UCL was first described by Dr. Frank Jobe in 1986. His primary reconstructive method involved detachment of the flexor-pronator musculature, submuscular transposition of the ulnar nerve and reconstruction of the UCL with a palmaris longus or plantaris tendon graft in a figure-8 configuration with repair of the flexor-pronator tenotomy[2]. The first successful procedure was performed on pitcher Tommy John in 1974. In Jobe's initial series of 16 patients he reported a return-to-play rate of 63%, with a complication rate of 32%, most commonly related to ulnar neuropathy[2]. In a follow-up series of 71 patients using the same reconstruction method, he noted 68% return to sport with a 21% complication rate[10].

While offering an improved outcome compared with conservative treatment or acute UCL repair, concern remained over the relatively high complication rate associated with Jobe's reconstructive method[10]. As a result, the modified Jobe technique was subsequently described by Smith *et al*[22], who introduced a flexor-pronator muscle-splitting approach that obviated the need for an obligatory ulnar nerve transposition and avoided tenotomizing the flexor-pronator origin. This modification resulted in an excellent outcome in 93% of a series of 83 athletes, with a 100% return to play rate[26]. Complications were reported in 5% and were limited to transient ulnar neuropathy, which resolved in all patients. It should be noted that while this approach no longer required a submuscular ulnar nerve transposition, many surgeons continue to perform subcutaneous ulnar nerve transpositions with the modified Jobe technique in select cases with preceding ulnar nerve symptoms, or routinely in all cases, depending on individual preference. Cain *et al*[27] reported on the outcomes of 743 patients that underwent UCL reconstruction utilizing the modified Jobe reconstruction with concomitant subcutaneous ulnar nerve transpositions. They identified an 83% return-to-play rate, and 20% complication rate. Notably, the authors of this study reported re-operation rates of 19% for residual posteromedial impingement.

As experience continued to grow in treating these injuries, concern was raised over the method of graft tensioning and fixation using the figure-of-8 configuration. Subsequently, Rohrbough *et al*[9] introduced a reconstruction method known as the docking technique to reduce the size of the humeral tunnels and improve fixation strength of the reconstruction. This procedure is performed through a muscle-splitting approach and does not require ulnar nerve transposition. It also involves looping the graft through a similar bone tunnel in the proximal ulna, however it differs in that both free limbs of the graft are then passed into a single tunnel on the humerus, with sutures exiting posteriorly through smaller drill holes, allowing the sutures to be tied over a posterior bony bridge. In addition, authors recommended routine elbow arthroscopy to treat concomitant pathology in the elbow joint, which was noted in up to 45% of patients[9]. In their index cohort of 36 patients, they reported a 92% return-to-play rate at the same level of competition, with only a 5.5% complication rate, including one transient ulnar neuropathy and one wound hematoma[9]. A larger follow-up study of 100 patients over 3 years revealed a 90% return to play rate, with only a 3% complication rate. Similarly, Paletta *et al*[28] described a modified docking technique utilizing a quadrupled, rather than doubled, palmaris graft, with slight differences in humeral bone tunnel preparation. Their procedure offered similar outcomes with 92% return to pre-injury level of competition, with slightly higher complication rates of 8%[28]. Additionally, Bowers *et al*[29] treated 21 overhead athletes with a modified docking technique using a triple-strand Palmaris graft. They had 19 (90%) excellent results, 2 good results, and no complications[29].

An additional modification attempted to address the inability of reconstruction techniques to restore the biomechanical strength comparable to the native ligament. Ahmad *et al*[30] identified improved fixation strength with cadaveric testing of a reconstructive technique using interference screw fixation, resulting in the development of a hybrid technique with ulnar interference screw fixation and humeral docking, known as the DANE TJ technique[31]. Otherwise, the procedure was unchanged, performed through a flexor-pronator muscle-splitting approach without ulnar nerve transposition. Results from the initial technique description, reported 86% return-to-play rates, with 18% complication rate of either transient ulnar neuropathy (9%) or post-operative adhesions requiring re-operation (9%)[31].

With many of these surgical techniques, there is concern over the size of the bone tunnels and the effect on graft tensioning and the potential for bone bridge compromise. A recent biomechanics study on 10 cadaveric elbows investigated the relationship graft size had on resistance to valgus load[32]. They found no significant difference in angular valgus deformation between palmaris longus, triceps brachii, extensor carpi radialis longus, and semitendinosus.

Further review of all available surgical technique descriptions and clinical series on UCL reconstructions was performed in two recent systematic reviews, which allowed for pooling of data to provide further comparative analysis between the different surgical techniques[3,4]. In the first review, Vitale *et al*[3] reported outcomes associated with different aspects of each surgical approach. They report that transitioning from a flexor-pronator detachment to a muscle-splitting surgical approach improved the success rates from 70% to 87%, while also reducing the rate of post-operative ulnar neuropathy from 20% to 6%. Additionally, adoption of the muscle-splitting approach reduced the need for an obligatory ulnar nerve transposition. Outcomes were noted to improve from a success rate of 75% in those who had an obligatory transfer to 89% in those who did not. Also, those undergoing an obligatory nerve transfer had a 9% rate of post-operative ulnar neuropathy, while only 4% of those who did not undergo a transposition reported the same. Finally, adoption of the docking and modified docking techniques also significantly improved outcomes with 90% and 95% of patients reporting excellent outcomes with these respective techniques, compared with only 76% of those undergoing reconstruction with the figure-of-8 technique. Similarly, a decrease in post-operative ulnar neuropathy rates was also noted among those undergoing docking and modified docking reconstructions compared with the figure-of-8 technique, with only 3% and 5% experiencing these complications in the docking groups while 8% of those with the figure-of-8 technique were observed to experience this complication.

A second systematic review by Watson *et al*[4] provided a comparison of the overall complication rates associated with each reconstructive technique. Cumulatively, when considering all reported outcomes from UCL reconstruction clinical series, they identified a complication rate of 16.6%, with the majority of these complications being ulnar neuropathy (12.9%). Further stratification of these results revealed different rates dependent on procedure, with the original Jobe reconstruction carrying a complication rate of 29.2%, while the modified Jobe technique carried a complication rate of 19.1%. The docking technique and modified docking technique had lower rates or 6% and 4.3% respectively.

Based on the results of these reported series and systematic analyses, it appears that newer reconstructive methods, including the docking and modified docking procedures, are associated with higher return-to-play rates and lower complication rates than earlier techniques, including the Jobe and modified Jobe techniques, as well as in comparison to the DANE TJ technique. Additionally, it appears that use of a muscle splitting surgical approach, without obligate ulnar nerve transposition, is also associated with improved outcome rates and lower complication rates. Finally, consideration should be given to both open or arthroscopic assessment and treatment of concomitant pathology, specifically posteromedial impingement, which was treated in 34%-45% of cases in larger volume series[3,11,27]. While no randomized trial exists to corroborate these conclusions, they are based on the best-available literature, including clinical data from over 1300 patients.

Adjunctive treatments

In addition to modifications in surgical techniques, basic science research is ongoing to determine if there are any adjunctive therapies that may expedite or improve the quality of tendon-to-bone healing following UCL reconstruction. As identified in both ACL reconstruction and rotator cuff repair surgery, the structure and composition of the insertion site is complex, with a gradual transition from tendon to bone with interposed unmineralized and mineralized fibrocartilage[33,34]. This architecture is typically not reconstituted in the normal healing process following ligament reconstruction or rotator cuff repair, although several attempts have been made at adding biologic agents to stimulate regenerative, rather than reparative, healing in both ACL and rotator cuff injuries.

For ACL injuries, addition of a collagen-platelet rich plasma scaffold following direct ligament repair was found to improve biomechanical and histologic properties of the healing ligament in both animals and humans[35,36]. Application of PRP following ACL reconstruction in animal models has also shown positive results in stimulating revascularization and re-innervation of the ACL graft[37,38]. Clinical results of PRP addition following ACL reconstruction have been less impressive, with only mild or no clinical improvement noted[39,40]. Similarly, stem cell use has also been studied in conjunction with ACL reconstruction, where addition of tendon-derived stem cell sheets and bioengineered periosteal progenitor cell sheets have demonstrated encouraging results in small animal models with improved fibrocartilage and bone formation at the tendon-bone junction, although clinical results are limited due to restrictions regarding stem cell utilization[41,42].

While there is a paucity of literature on the effect of these various orthobiologic agents in UCL reconstruction, results of the literature for both ACL reconstruction and rotator cuff repair can potentially be extrapolated to this group. Further study is necessary to see if these biologic agents can potentially improve or expedite healing to allow for improved clinical outcomes and lower re-injury rates.

Figure 1 Modified sleeper stretch. The athlete lies on her side with her scapula retracted, rotates slightly posteriorly to place the shoulder in the scapular plane (dashed line), and passively internally rotates the shoulder until a mild stretch is felt. Hold for 30 s, relax, and repeat 3 times.

POST-OPERATIVE

Every athlete who is evaluated for an ulnar collateral ligament injury should have a thorough evaluation of all intrinsic and extrinsic factors that can contribute to valgus instability. It is important to address poor mechanics related to underlying factors, including capsular stiffness in glenohumeral internal rotation deficit (GIRD), scapular dyskinesis, and deficiencies of core and single leg strength. Post-operative and nonsurgical treatment are related to the restoration of normal scapulohumeral rhythm, which begins with establishing trunk and core stability, elbow range of motion and strength, as well as using triplanar exercises, including lunges and balance exercises[43].

GIRD should be evaluated by stabilizing the scapula, placing the arm in 90° of abduction in the scapular plane, and internally and externally rotating the arm. Bilateral measurements should be obtained, and treatment initiated if the side-to-side difference in the total arc of rotational motion is greater than 5°[44]. Modified sleeper stretches and modified side-lying

Figure 2 Modified side-lying cross body stretch. The athlete lies on the affected shoulder and stabilizes the scapula by rotating posteriorly (dashed line) against the table as the shoulder is horizontally adducted (arrow). External rotation is restricted *via* counter pressure of the opposite forearm. Hold for 30 s, relax, and repeat 3 times.

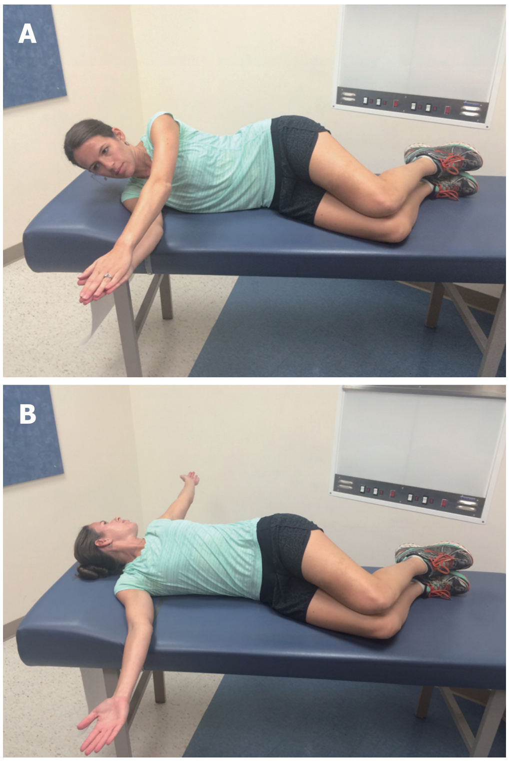


Figure 3 Open book stretch. A: The athlete lies on the unaffected shoulder with hips and knees bent 90° and arms straight out in front of him; B: Opening the chest and laying the affected extremity on the opposite side and looking in the same direction stretches the pectoralis major and biceps short head. Hold for 90 s, relax, and repeat 3 times.

cross body are excellent for improving GIRD[45,46]. The modified sleeper stretch is performed in the lateral position with the patient lying on the affected extremity using their unaffected arm to stretch the posterior capsule (Figure 1). The modification of rotating slightly posteriorly stabilizes the scapula without causing subacromial impingement. The modified side-lying cross body stretch is performed in the lateral position with the athlete lying on the affected extremity, using the opposite hand to horizontally adduct the targeted shoulder (Figure 2). The opposite forearm is aligned on top and restricts external rotation of the humerus. The side-lying position stabilizes the scapula and resists scapular protraction allowing optimal stretch of the posterior shoulder. Each of these stretches are held for 30 s and repeated 3 times. There is evidence that the side-lying cross body stretch is more effective than the sleeper stretch[45,46].

The open book and corner stretches can improve pectoralis minor and biceps short head flexibility. The open book stretch is performed in the lateral position lying on the unaffected extremity with the patient's knees bent and arms stretched out in front. Opening the chest and laying the affected extremity on the opposite side and looking in the same direction stretches the pectoralis major and biceps short head (Figure 3). The corner stretch is performed facing a corner with the shoulders abducted and elbows flexed to 90° and the athlete slowly leans into the corner (Figure 4). Each of these stretches are held for 90 s and repeated 3 times.

Figure 4 Corner stretch. The athlete faces a corner with the shoulders abducted, elbows flexed to 90° and slowly leans into the corner. Hold for 90 s, relax, and repeat 3 times.

Table 2 Airfield surface movement indicator postoperative rehabilitation protocol following ulnar collateral ligament reconstruction with palmaris longus autograft

Time period	Phase	Goal
Day 0-7	Splinted at 90° flexion	Early healing of graft and fascial sling for nerve transposition
Weeks 1-5	Hinged elbow ROM brace	Protect healing tissues from valgus stress
Weeks 3-4	Light resistance isotonic exercises	Develop dynamic stabilization of the medial elbow
Week 6	Thrower's Ten Program	
Weeks 8-9	Progressive resistance exercises incorporated	
Week 12	Advanced Thrower's Ten Program Two-hand plyometric drills	
Week 14	One-hand plyometric drills	
Week 16	Interval throwing program	
Week 22/24	Throwing from the mound	
Months 9-12	Return to competitive throwing	

ROM: Range of motion.

Scapular dyskinesis is characterized by loss of upward acromial rotation, excessive scapular internal rotation, and excessive scapular anterior tilt[47]. These positions create scapular protraction, which decreases demonstrated rotator cuff strength[48]. Evaluation of scapular dyskinesis is accomplished by observation of static position and dynamic motions. The emphasis for rehabilitation for ulnar collateral ligament injuries should start proximally and end distally. Proximal control of core stability leads to control of three-dimensional scapular motion, with a goal to achieve the position of optimal scapular function - posterior tilt, external rotation, and upward elevation[43]. The serratus anterior functions most importantly as an external rotator of the scapula, and the lower trapezius acts as a stabilizer. Maximal rotator cuff strength is achieved from a stabilized, retracted scapula[49]. Periscapular strengthening should be accomplished by taking advantage of the synergistic activity of proximal trunk and hip muscle activation[49]. Exercise sets should include lawn mower pulls and low row exercises[49].

Kinetic chain factors may be evaluated by screening methods. Hip and trunk stability can be assessed using the single leg stance and single leg squat maneuvers[43]. In the single leg stance test, a positive Trendelenburg sign indicates gluteus medius weakness. Forward or lateral trunk tilt or rotation of the trunk around the leg in a single leg squat maneuver indicates a loss of dynamic control. Lunge and balance exercises should be incorporated into a rehabilitation program to improve trunk and core stability.

Rehabilitation programs vary institutionally and by treating physician. There is currently no validated comprehensive program. Rehabilitation following elbow injury or elbow surgery should follow a sequential and progressive multiphased approach that involves a gradual and protected return of ROM and an extensive resistance exercise program for the entire upper extremity kinetic chain. The rehab program should include proprioceptive exercises to stimulate mechanoreceptors as well as total arm strengthening, emphasizing proximal scapular stabilization. Low-resistance, high-repetition programs promote an optimal return to uncompensated throwing.

Phase 1 involves immediate motion. Reestablishing full elbow extension, typically defined as preinjury motion, is the primary goal of early ROM activities. Another goal of this phase is to decrease pain and inflammation. Modalities including cryotherapy, high voltage stimulation, and laser therapy can be helpful. Once the acute inflammatory response has subsided, moist heat, warm whirlpool, and ultrasound may be used at the beginning of treatment to prepare the tissue for stretching[50]. If the patient continues to have difficulty achieving full extension using ROM and mobilization techniques, a low load, long duration stretch may be performed to aid tissue elongation[50]. Submaximal isometrics are performed initially for the elbow flexor and extensor, as well as the wrist flexor, extensor, pronator, and supinator muscle groups. Scapular strengthening and activation exercises are also initiated immediately following surgery.

Phase 2, the intermediate phase, starts when the patient exhibits full ROM with minimal pain and involves improving muscular strength and endurance and reestablishing neuromuscular control of the elbow. Particular emphasis is placed on shoulder external and internal rotation at 90° abduction. External rotation helps avoid increased strain on the medial elbow structures during the overhead throwing motion[51] while internal rotation may create a protective varus force at the elbow[50]. A complete upper extremity strengthening program, such as the Thrower's Ten Program, which focuses on the muscles needed for dynamic stability, should be included[52] (Figure 5).

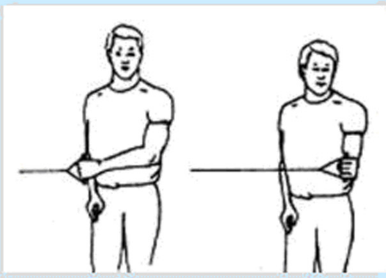
Phase 3 encompasses advanced strengthening in preparation for a gradual return to sport. To enter this phase, the athlete must demonstrate strength that is 70% of the contralateral extremity. The advanced Thrower's Ten Program[53] is used at this stage and involves exercises based on the principles of coactivation, dynamic stabilization, muscular facilitation, endurance, and coordination[53].

Phase 4, the final phase, involves an interval throwing program allowing the athlete to return to full competition. These throwing programs are sport specific and differ for golf and tennis athletes[54]. Isokinetic testing is commonly performed at this stage to determine the readiness of the athlete for an interval throwing program[54]. The interval throwing program has two phases, beginning with progressive long tosses and ending with throwing off the mound. The validity of this order has been questioned as some believe that long toss creates more stress at the medial elbow when

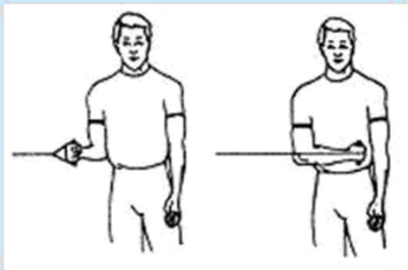
1A. Diagonal Pattern D2 Extension: Involved hand will grip tubing handle overhead and out to the side. Pull tubing down and across your body to the opposite side of leg. During the motion, lead with your thumb. Perform _____ sets of _____ repetitions _____ daily.

1B. Diagonal Pattern D2 Flexion: Gripping tubing handle in hand of involved arm, begin with arm out from side 45° and palm facing backward. After turning palm forward, proceed to flex elbow and bring arm up and over involved shoulder. Turn palm down and reverse to take arm to starting position. Exercise should be performed _____ sets of _____ repetitions _____ daily.

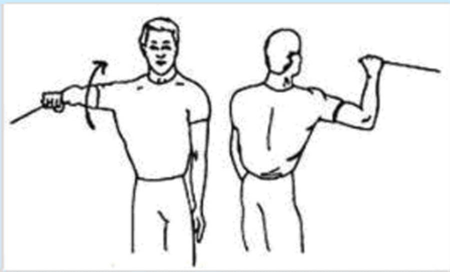
2A. External Rotation at 0° Abduction: Stand with involved elbow fixed at side, elbow at 90° and involved arm across front of body. Grip tubing handle while the other end of tubing is fixed. Pull out arm, keeping elbow at side. Return tubing slowly and controlled. Perform _____ sets of _____ repetitions _____ times daily.



2B. Internal Rotation at 0° Abduction: Standing with elbow at side fixed at 90° and shoulder rotated out. Grip tubing handle while other end of tubing is fixed. Pull arm across body keeping elbow at side. Return tubing slowly and controlled. Perform _____ sets of _____repetitions _____ times daily.



2C. (Optional) External Rotation at 90° Abduction: Stand with shoulder abducted 90°. Grip tubing handle while the other end is fixed straight ahead, slightly lower than the shoulder. Keeping shoulder abducted, rotate shoulder back keeping elbow at 90°. Return tubing and hand to start position.
I. Slow Speed Sets: (Slow and Controlled) Perform _____ sets of _____ repetitions _____ times daily.
II. Fast Speed Sets: Perform _____ sets of _____ repetitions _____ times daily.



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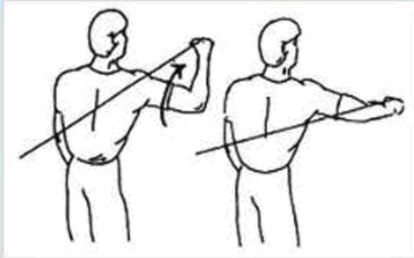
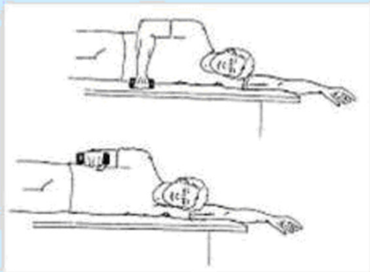
2D. (Optional) Internal Rotation at 90° Abduction: Stand with shoulder abducted to 90°, externally rotated 90° and elbow bent to 90°. Keeping shoulder abducted, rotate shoulder forward, keeping elbow bent at 90°. Return tubing and hand to start position.
I. Slow Speed Sets: (Slow and Controlled) Perform _____ sets of _____ repetitions _____ times daily.
II. Fast Speed Sets: Perform _____ sets of _____ repetitions _____ times daily.



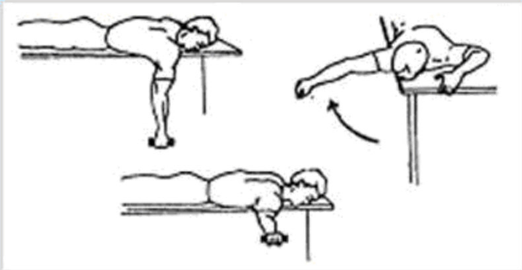
3. Shoulder Abduction to 90°: Stand with arm at side, elbow straight, and palm against side. Raise arm to the side, palm down, until arm reaches 90° (shoulder level). Perform _____ sets of _____ repetitions _____ times daily.

4. Scaption, External Rotation: Stand with elbow straight and thumb up. Raise arm to shoulder level at 30° angle in front of body. Do not go above shoulder height. Hold 2 seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.

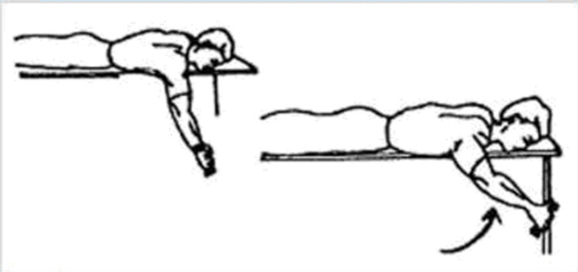
5. Sidelying External Rotation: Lie on uninvolved side, with involved arm at side of body and elbow bent to 90°. Keeping the elbow of involved arm fixed to side, raise arm. Hold seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.



6A. Prone Horizontal Abduction (Neutral): Lie on table, face down, with involved arm hanging straight to the floor, and palm facing down. Raise arm out to the side, parallel to the floor. Hold 2 seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.

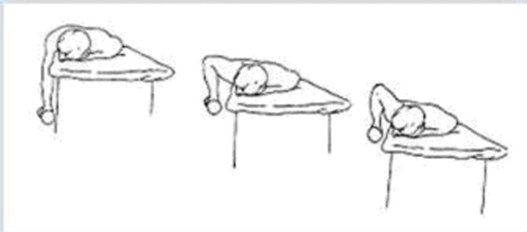


6B. Prone Horizontal Abduction (Full ER, 100° ABD): Lie on table face down, with involved arm hanging straight to the floor, and thumb rotated up (hitchhiker). Raise arm out to the side with arm slightly in front of shoulder, parallel to the floor. Hold 2 seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.

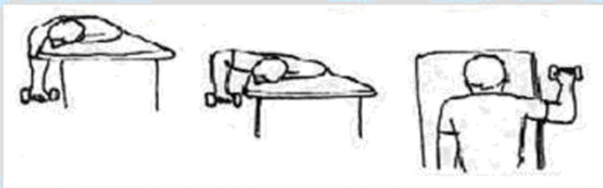


(continued)

6C. Prone Rowing: Lying on your stomach with your involved arm hanging over the side of the table, dumbbell in hand and elbow straight. Slowly raise arm, bending elbow, and bring dumbbell as high as possible. Hold at the top for 2 seconds, then slowly lower. Perform _____ sets of _____ repetitions _____ times daily.

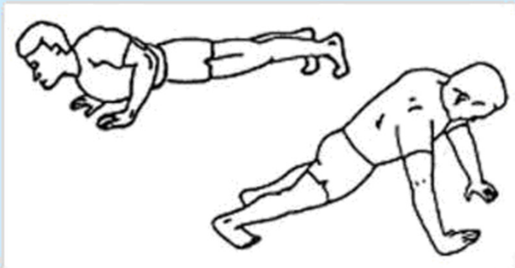


6D. Prone Rowing Into External Rotation: Lying on your stomach with your involved arm hanging over the side of the table, dumbbell in hand and elbow straight. Slowly raise arm, bending elbow, up to the level of the table. Pause one second. Then rotate shoulder upward until dumbbell is even with the table, keeping elbow at 90°. Hold at the top for 2 seconds, then slowly lower taking 2 – 3 seconds. Perform _____ sets of _____ repetitions _____ times daily.



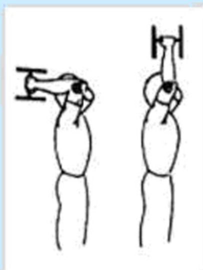
7. Press-ups: Seated on a chair or table, place both hands firmly on the sides of the chair or table, palm down and fingers pointed outward. Hands should be placed equal with shoulders. Slowly push downward through the hands to elevate your body. Hold the elevated position for 2 seconds and lower body slowly. Perform _____ sets of _____ repetitions _____ times daily.

8. Push-ups: Start in the down position with arms in a comfortable position. Place hands no more than shoulder width apart. Push up as high as possible, rolling shoulders forward after elbows are straight. Start with a push-up into wall. Gradually progress to table top and eventually to floor as tolerable. Perform _____ sets of _____ repetitions _____ times daily.



9A. Elbow Flexion: Standing with arm against side and palm facing inward, bend elbow upward turning palm up as you progress. Hold 2 seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.

9B. Elbow Extension (Abduction): Raise involved arm overhead. Provide support at elbow from uninvolved hand. Straighten arm overhead. Hold 2 seconds and lower slowly. Perform _____ sets of _____ repetitions _____ times daily.



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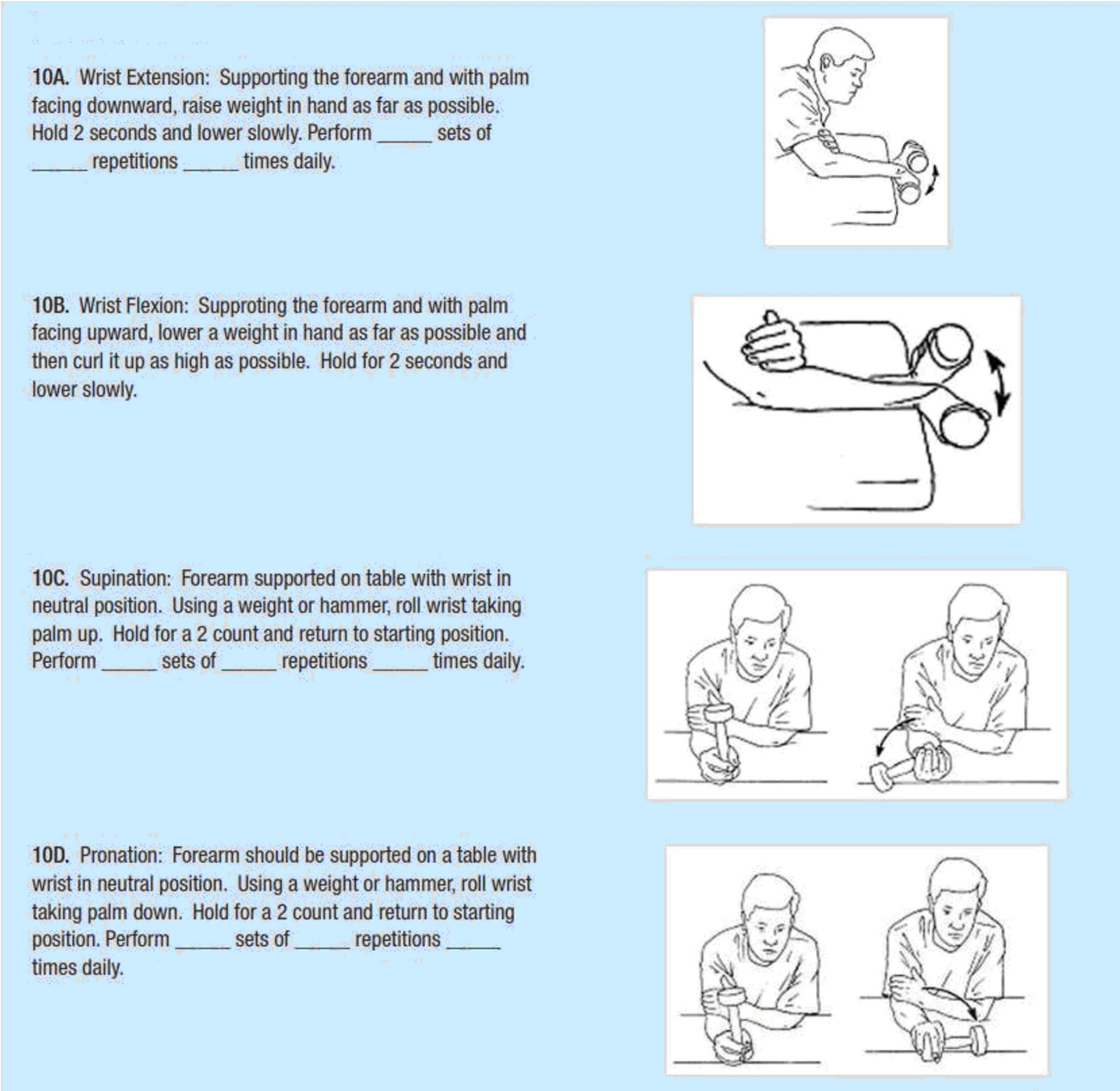

Figure 5 Thrower's ten program. The Thrower's Ten Program is designed to exercise the major muscles necessary for throwing. The Program's goal is to be an organized and concise exercise program. In addition, all exercises included are specific to the thrower and are designed to improve strength, power, and endurance of the shoulder complex musculature.

compared with off the mound throwing.

Specific postoperative rehabilitation guidelines are based on the operative technique used for UCL reconstruction. The rehabilitation program used at the Andrews Sports Medicine Institute is outlined in Table 2[50] and the rehabilitation program used at Hospital for Special Surgery is outlined in Table 3[50]. Dynamic stabilization of the medial elbow is accomplished by concentric and eccentric strengthening the flexor carpi ulnaris and flexor digitorum superficialis. Given their anatomic location overlying the UCL, these muscles assist the UCL in stabilizing valgus stress at the medial elbow[50].

Injury to the UCL most commonly occurs in baseball pitchers, but is also seen in other subsets of athletes, including javelin throwers, football quarterbacks and softball pitchers. Each sport requires different throwing mechanics and imparts different stresses to the elbow due to the varied angular velocities produced at the elbow (Table 4). Rehabilitation protocols should be sport specific and take into account the unique movements associated with these activities.

The javelin event involves throwing a 2.6-m spear weighing at least 800 g. Throwers lengthen the path of acceleration by maintaining an extended elbow for as long as possible until foot strike[55]. The throwing motion is broken down into four phases: Approach run, cross steps, delivery stride, and thrust phase. During

Table 3 High speed steels postoperative rehabilitation protocol following ulnar collateral ligament reconstruction with palmaris longus autograft

Time period	Treatment strategies	Goal
Day 0-10	Splinted or hinged elbow ROM brace at 60 degrees flexion	Promote graft healing, reduce pain, and swelling
Weeks 1-4	Hinged elbow ROM brace at all times No PROM Elbow AROM in brace	Restore ROM 30°-90° Promote graft healing Independent home exercise program
Weeks 4-6	Continue brace wear at all times Avoid PROM Avoid valgus stress Continue AROM in brace Isometric exercises of deltoid, wrist, elbow	Restore ROM 15°-115° Minimal pain and swelling
Weeks 6-12	Minimize valgus stress Avoid PROM by the clinician Avoid pain with exercises Continue AROM Low intensity, long duration stretch for extension Isotonic exercises of the scapula, shoulder, elbow, forearm and wrist Eccentric training when strength is adequate	Restore full ROM All upper extremity strength 5/5 Begin to restore muscular endurance
Week 8	Begin internal/external rotation strengthening Begin forearm pronation/supination strengthening	
Weeks 12-16	Pain free plyometric exercises Advance internal/external rotation to 90/90 position Neuromuscular drills Plyometric program Endurance training	Restore full strength and flexibility Prepare for return to activity
Week 16	Begin interval throwing program	
Weeks 16-36	Avoid pain with throwing or hitting Avoid loss of strength or flexibility Continue flexibility training Continue strengthening program	Return to activity Prevent reinjury
Week 20	Begin hitting program	

ROM: Range of motion; AROM: Active range of motion; PROM: Passive range of motion.

Table 4 Angular velocity by sport

Sport	Baseball	Softball	Football	Javelin	Tennis
Angular velocity	2400°/s	570°/s	1760°/s	1900°/s	982°/s

the thrust phase, the elbow flexes from 40°-60°[55]. As contrasted with baseball pitchers who undergo rapid extension, javelin throwers undergo rapid flexion. Although throwing a javelin and pitching a baseball both produce large valgus forces on the medial side of the elbow, leading to UCL injuries, the mechanics of throwing are vastly different. Perhaps there should be changes to post-operative protocols that specifically address these specialized movement differences. No consensus postoperative protocol and throwing program exists for javelin throwers in the literature. As a javelin is much heavier than a baseball (1.76 pounds *vs* 0.32 pounds), we prefer to wait 8 mo from surgery (as compared to 4 in baseball pitchers) to begin an interval throwing program. We also recommend focusing more on lower extremity core strengthening to account for the increased weight of the javelin. Javelin throwers should be counseled that due to their unique motion and weight of the javelin, their return to play will be longer than in baseball players, and should be expected around 15 mo.

The motion of throwing a football is similar to throwing a baseball pitch. The lower incidence of elbow injuries in football quarterbacks is multifactorial. With a larger size ball, arm velocities are much slower, therefore producing less stress. The motion is also more over-the-top which produces less valgus force at the elbow. It is also hypothesized that the follow-through phase is abbreviated as the quarterback needs to be prepared for the impact from an opposing player, possibly lowering forces and torques produced at the elbow. Finally, quarterbacks perform the throwing motion significantly few times per game and per season compared to major league pitchers, and therefore are cumulatively placing less stress on their elbows. While some quarterback UCL injuries are chronic, the vast majority in the literature are from acute contact injuries[56,57]. Results from Dodson *et al*[56] and Kenter *et al*[57] suggest that these players can be successfully treated nonoperatively and return to competitive play.

Softball pitchers are a unique subset of throwers due to the underhand nature of their motion. While the overhead thrower is extending the elbow at ball release, the underhand softball pitcher is flexing the elbow. Although reasons are unclear, the female athlete, especially the underhand softball pitcher, imparts less stress to the elbow, making the injury more amenable to repair[58]. There is some evidence to suggest positive outcomes in ligament reconstruction for these athletes. However, the data on these athletes lacks the data that we have for their male counterparts. Further research into female throwing injuries is necessary. Currently, repair is a viable option.

UCL injuries have also been reported tennis, gymnastics, wrestling, volleyball and in baseball position players[27]. The demands of their sports and positions result in a much lower frequency of injury and usually do not necessitate UCL reconstruction for return to play. Further research is needed to investigate sport-specific protocols and treatment outcomes for athletes who play sports that place the UCL at risk.

CONCLUSION

We still need to answer the unknown. For example, currently we throw long-toss before mound throwing. There is some evidence to support that this actually puts more stress on the UCL reconstruction. Return to sport at the same or higher level may be easier for a high school athlete compared to a professional pitcher, but currently these are not differentiated in the literature. In order to have functional screening and quantitative return to play after UCL reconstruction like we currently have for ACL reconstruction, we need to know what is normal at every level of participation and position, including professional, college, high school athletes as well as distinctions between pitchers *vs* position players.

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MINIREVIEWS

Sternoclavicular joint dislocation and its management: A review of the literature

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Abstract

Dislocations of the sternoclavicular joint (SCJ) occur with relative infrequency and can be classified into anterior and posterior dislocation, with the former being more common. The SCJ is inherently unstable due to its lack of articular contact and therefore relies on stability from surrounding ligamentous structures, such as the costoclavicular, interclavicular and capsular ligaments. The posterior capsule has been shown in several studies to be the most important structure in determining stability irrespective of the direction of injury. Posterior dislocation of the SCJ can be associated with life threatening complications such as neurovascular, tracheal and oesophageal injuries. Due to the high mortality associated with such complications, these injuries need to be recognised acutely and managed promptly. Investigations such as X-ray imaging are poor at delineating anatomy at the level of the mediastinum and therefore CT imaging has become the investigation of choice. Due to its rarity, the current guidance on how to manage acute and chronic dislocations is debatable. This analysis of historical and recent literature aims to determine guidance on current thinking regarding SCJ instability, including the use of the Stanmore triangle. The described methods of reduction for both anterior and posterior dislocations and the various surgical reconstructive techniques are also discussed.

Key words: Sternoclavicular joint dislocation; Reduction; Reconstruction; Stabilisation; Surgery

Core tip: Most anterior sternoclavicular joint (SCJ) dislocations can be managed non-surgically. A small subgroup of these patients develop persistent symptomatic anterior instability. While most tolerate these symptoms well some find this disabling and surgical stabilisation in such cases have shown satisfactory results. Posterior SCJ dislocation can be subtle and needs prompt identification and immediate closed reduction but if unstable will require surgical stabilisation.

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INTRODUCTION

Sternoclavicular joint dislocations are rare and represent only 3% of all dislocations around the shoulder[1]. Despite the uncommon nature of these injuries they can present the clinician with uncertainty regarding their investigation and management. Dislocations may be either traumatic or atraumatic. Those that are due to trauma may dislocate anteriorly or posteriorly, with anterior dislocation being approximately nine times more common. The main concern with a posterior dislocation is the risk of compression to the mediastinal structures which may be life threatening, requiring expedient intervention[2]. Atraumatic dislocations and subluxations may occur in patients with collagen deficiency conditions such as generalised hypermobility syndrome and Ehlers-Danlos[3,4], or clavicular deformity, abnormal muscle patterning, infection or arthritis. The purpose of this educational review is clarify the current thinking regarding the diagnosis of all types of sternoclavicular joint (SCJ) dislocation and how these challenging injuries can be managed[5].

ANATOMY

The SCJ is the only bony articulation between the axial skeleton and the upper extremity[6]. The clavicle is unique in the sense that it is the first bone in the human body to ossify, usually in the fifth gestational week but the medial end of the clavicle is the last to fuse, between ages 23-25[7]. Therefore in some patients under 25, what is believed to be an SCJ dislocation is actually a fracture of medial clavicular physis and owing to the remodelling potential of such paediatric injuries can usually be managed conservatively[8].

The SCJ is a diarthrodial saddle type synovial joint which is inherently unstable[8,9]. Less than 50% of the medial clavicular surface articulates with its corresponding articular surface on the manubrium sterni. Its stability is therefore derived from intrinsic and extrinsic ligamentous structures surrounding the joint[8]. These structures include the costoclavicular (rhomboid) ligament, which is divided into an anterior and posterior fasciculus. The anterior fasciculus resists superior rotation and lateral displacement and the posterior fasciculus resists inferior rotation and medial displacement. The interclavicular ligament (extrinsic) and the posterior and anterior sternoclavicular ligaments also aid stability along with the anterior and posterior capsular ligaments. In 1967, Bearn[10] conducted an anatomical study looking at the structures which were of paramount importance in maintaining SCJ stability. By dividing all the ligamentous structures except the capsular restraints there was found to be no effect on the position of the clavicle. However dividing the capsular ligaments in isolation resulted in a superior migration of the medial clavicle. This work was repeated by Spencer *et al*[6] in 2002 and showed that the posterior capsule is the joints strongest ligamentous stabiliser. Sectioning of the posterior capsule resulted in 41% increase in anterior translation and a 106% increase in posterior translation. When the anterior capsule was cut in isolation this resulted in just a 25% increase in anterior translation and 0.7% increase in posterior translation. Therefore in reconstructive surgery close attention should be paid to the posterior capsule whether the dislocation is anterior or posterior[6].

The SCJ contains a fibrocartilagnous disc which is attached to the anterior and posterior sternoclavicular ligaments and capsule, dividing the SCJ into two synovium-lined cavities[8]. This disc degenerates with time and by the patients 70’s or 80’s is incomplete[11]. Tears of this disc can be a cause of pain in the younger patient.

Subclavius arises from the first rib just lateral to the costoclavicular ligament and inserts onto the inferior surface of the clavicle. It is believed to have a protective function with regards to the stability of the SCJ by reducing the rate of upward displacement of the clavicle when it is under lateral compressive loads[8].

BIOMECHANICS

Any movement at the shoulder girdle results in some degree of movement at the SCJ. The clavicle elevates about 4 degrees for every 10 degrees of arm forward flexion[12]. When the shoulders are retracted the SCJ translates anteriorly and the reverse for shoulder protraction. With combined movements the clavicle can rotate up to 40 degrees along its longitudinal axis. Patients with a short clavicle can result in significantly more torque at the SCJ[8].

Posterior dislocation of the SCJ can be caused by a direct force over the anteromedial aspect of the clavicle or an indirect force to the posterolateral shoulder, forcing the medial clavicle posteriorly. Anterior dislocation is usually due to a lateral compressive force to the shoulder girdle, which results in sparing of the posterior capsule but rupture of the anterior capsule and often part of the costoclavicular ligament. As with all high energy injuries one should have a high index of suspicion for associated injuries[8].

CLINICAL PRESENTATION

Patients presenting with these injuries are often in high energy collisions, whether that be sporting or through a motor vehicle accident[13]. Those with anterior dislocations of the SCJ will complain of a painful lump just lateral to the sternum. Care needs to be taken to determine whether this is indeed a true dislocation or a fracture of the medial clavicle. As mentioned previously,

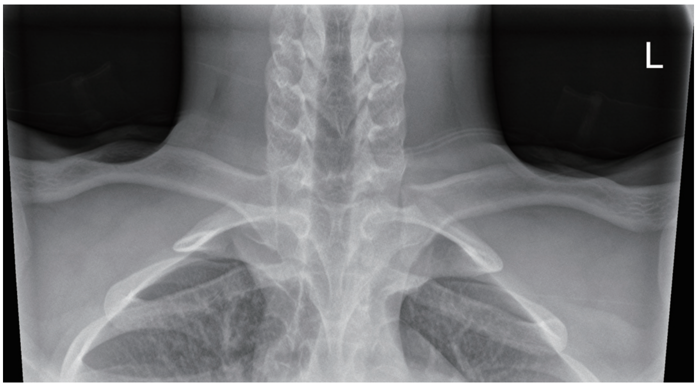

Figure 1 Serendipity view.

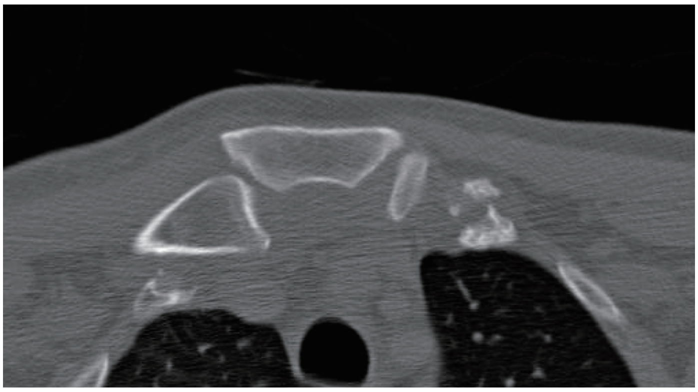

Figure 2 Computed tomography scan showing dislocation of the sternoclavicular joint.

if the patient is under 25 then consideration of the possibility of this being a physeal injury should be undertaken[9].

Posterior dislocations present with medial clavicular pain but also may present with compressive symptoms such as dyspnoea or dysphagia or with vascular and neurological compromise. If any of these symptoms are present then urgent reduction is necessary. Patients often have the affected upper limb adducted across their chest to prevent excess glenohumeral or scapulo-thoracic movements. There will often be minimal swelling but may be some bruising below the medial aspect of the clavicle[8].

On examination patients will have evidence of swelling and reduced upper limb range of movement. They may also present with new onset paraesthesia in the upper limb and/or weakened pulses or signs of venous congestion.

INVESTIGATIONS

Dislocations of the SCJ are notoriously difficult to visualise on plain radiographs. Routine chest radiographs have a poor sensitivity for picking up dislocations, however they mandatory if there is a suspicion of a posterior dislocation so as to rule out a pneumothorax, pneumomediastinum or haemopneumothorax[8]. In 1975, Rockwood[14] described the "serendipity" view (Figure 1) or 40 degree cephalic tilt which presents the anterior dislocation as a superiorly displaced medial clavicle and the posterior dislocation as an inferiorly displaced medial clavicle. Alternative views include the Heinig view, in which the X-ray beam is directly perpendicular to the SCJ but with an oblique projection in the supine patient[15]. This allows the SCJ to be visualised without underlying vertebral bodies distorting the view.

CT imaging is readily available 24 h a day in most trauma units and this is the investigation of choice (Figure 2). It has superior image resolution and allows 3D reconstruction of the SCJ to determine its exact position[16] (Figure 3). MRI has a poorer resolution than CT but can be used to assess ligamentous injury and the condition of the other soft tissues posterior to the SCJ[8].

If there is a suspicion of an intimal tear to the subclavian artery then CT angiography may be necessary.

CLASSIFICATION

Dislocations of the SCJ can be broadly classified by the direction of displacement, which may be anterior or posterior, superior or inferior. Dislocation of the SCJ is often not an isolated event and may be due to other structural causes than trauma. It can therefore be thought of as instability, which can be acute, recurrent or persistent. The Stanmore triangle, which is commonly used for glenohumeral instability, has also been applied to instability of the SCJ. The triangle consists of 3 polar groups; type Ⅰ traumatic structural, type Ⅱ atraumatic structural and type Ⅲ muscle patterning, non structural. Patients may move around this triangle with time, for example a patient may initially present with a clear

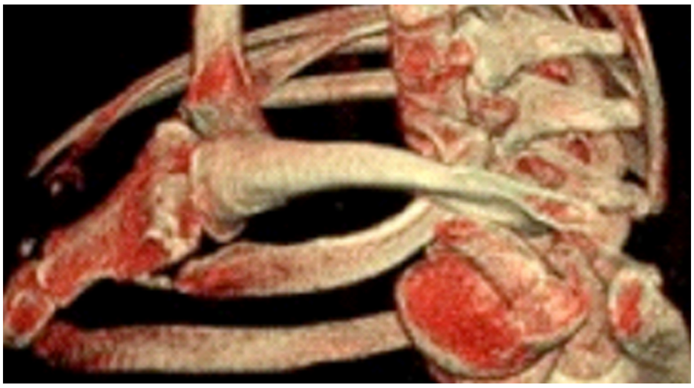

Figure 3 Computed tomography reconstruction of the sternoclavicular joint dislocation.

traumatic event but then as a result of abnormal movement due to pain may develop abnormal muscle patterning[8].

With type I instability there is a clear history of trauma, whether this is a fracture of the medial clavicle or SCJ dislocation. With Type II there is no history of trauma but structural change within the capsular tissue, which may be as a result of repetitive microtrauma. In type III there is no structural abnormality and it is the abnormal contraction of muscles, namely pectoralis major, which cause the SCJ to sublux or dislocate[8].

MANAGEMENT

Reduction of anterior dislocation

If the patient presents with an acute anterior dislocation of their SCJ (within 7-10 d) then these can be reduced by closed reduction with sedation or under general anaesthetic in the operating room. The patient is placed supine with a bolster placed between their shoulders. Traction is then applied to the affected upper limb in 90 degrees of abduction with neutral flexion and direct pressure is applied over the medial clavicle. Following reduction the arm should be placed in a polysling, maintaining scapular protraction for up to 4 wk. Re-dislocation has found to range between 21% and 100%[17-19] which raises the question whether simple closed reduction without ligament reconstruction is sufficient. One can also question whether reduction of an anterior dislocation is necessary at all.

Bicos *et al*[20] argues that anterior SCJ instability should primarily be treated conservatively. The patients should be informed there is a high risk of persistent instability with non-operative treatment, but this persistent instability will be well tolerated and have little functional impact in the vast majority. Most anterior SCJ instability can be managed without surgery. However a small sub group of these patients go on to develop persistent symptomatic instability requiring surgical stabilisation.

Reduction of posterior dislocation

Although these injuries are rare, complications such as oesophageal, tracheal or neurovascular injury occur in approximately 30% with a mortality rate of 3%-4%[18].

Closed reduction under sedation should be attempted in patients presenting in the acute phase (within 7-10 d). Rockwood[14] described a technique of reduction in which a towel clip is used percutaneously to grasp the medial clavicle and pull it anteriorly.

An alternative reduction tool is the abduction traction technique. The shoulder is abducted to 90 degrees and traction applied. An extension force is then applied to the shoulder resulting in anterior translation of the medial clavicle back into joint[21].

In 1984 Buckerfield *et al*[22] suggested a technique involving retraction of the shoulders with caudal traction on the adducted arm, while the patient is supported by an interscapular bolster. This achieved reduction in 6 out of 7 patients who had failed reduction through other means.

Open reduction and stabilisation

If closed reduction is not possible or there is on going symptomatic instability of the SCJ, there are numerous surgical techniques that have been described in the literature and there is no evidence that one method is superior over the other. Martínez *et al*[23] describe a technique used in 1 posterior dislocation using gracilis tendon passed in a figure of 8 through drill holes in the manubrium and clavicle. At 1 year follow-up there was evidence of SCJ subluxation and erosion of both the manubrium and medial clavicle. Despite this patient was asymptomatic.

Booth *et al*[24] reported a more successful technique in 5 SCJ's. The sternal origin of the sternocleidomastoid (SCM) with a strip of periosteum is detached and passed under the first rib and back through a drill hole in the clavicle and then tied back onto itself. In this way it has effectively reconstructed the costoclavicular ligament. No complications or failures were noted in this group.

Bae *et al*[25] presented 15 cases in which either semitendinosus or SCM graft was passed through the medial clavicle and manubrium in a figure of 8. The medial 2-2.5 cm of clavicle was then resected. Results were mixed with 87% of patients achieving stability but 40% of patients complained of persistent pain.

More recently, Abiddin *et al*[26] had success with the use of suture anchors, avoiding the need for graft.

Figure 4 Surgilig lockdown device.

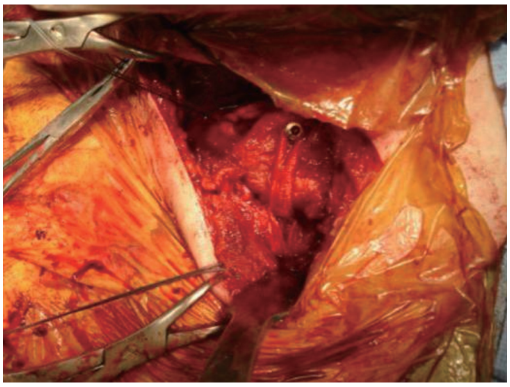

Figure 5 Intraoperative picture of sternoclavicular joint stabilisation using surgilig lockdown.

Sutures were placed through drill holes in the medial clavicle and manubrium combined with a capsular repair. He reported 2 failures, one of which was traumatic.

Franck *et al*[27] reported excellent results with the use of a Balser plate. The hook of this was inserted under the manubrium with the lateral aspect of the plate lying on the medial clavicle. No re-dislocations were reported in any of the 9 patients however metalwork needed to be removed a secondary procedure to prevent migration.

Wallace *et al*[28] reported their new technique of stabilising the SC joint by reconstructing the costoclavicular ligament using a braided polyester mesh device (Surgilig Lockdown) (Figures 4 and 5). In a separate study they had looked at the histological response of the braided polyester mesh device retrieved from AC joint and found outer capsule formation composed of collagen with fibroblast. This technique recreates the costoclavicular ligament and also stabilises the anterior and the posterior capsule during stabilisation. Their results showed no major or life threatening complication and all patients achieved good functional outcome and patient satisfaction[28-30].

An important lesson was learned through the work of Lyons *et al*[31]. Rather than a soft tissue procedure they described the use of smooth and threaded k wires to stabilise 21 anterior SCJ dislocations. The results were catastrophic with 8 deaths due to wire migration into major vascular structures. A further 6 patients only survived cardiac tamponade following surgical intervention. In later work Rockwood *et al*[32] described excision arthroplasty of the medial 1.5 cm of the clavicle. However, he found that in those with a ruptured CCL requiring reconstruction then excision of the medial clavicle was unsatisfactory.

In patients with type Ⅱ instability of the SCJ, the usual presentation is prominence of the medial clavicle and pain felt on overhead activities. There is often a history of generalised ligamentous laxity. This group of patients can usually be managed with steroid injections and physiotherapy alone. Rockwood *et al*[33] looked at patients with atraumatic anterior dislocations and found that when treated conservatively 78% of patients had no restriction of lifestyle or activity, however 90% had persistent subluxation and 21% of these had ongoing pain. Patients treated surgically all showed unsatisfactory results. Atraumatic posterior dislocations should be treated in a similar way to traumatic dislocations with open reduction and stabilisation due to the risk of compression to retrosternal structures.

Surgery is rarely indicated in type Ⅲ instability of the SCJ. The problem is non-structural and due to abnormal muscle patterning. They may be investigated using EMG's to identify if the pectoralis major is being recruited inappropriately. Management is therefore with biofeedback physiotherapy which requires patient compliance and the re-learning of appropriate muscle contraction and proprioception[34]. Surgery should be reserved for those patients who demonstrate some structural abnormality which has then gone on to develop abnormal muscle patterning (type Ⅱ/Ⅲ)[8].

COMPLICATIONS

The main recognised complications are associated with traumatic posterior dislocations of the SCJ. Symptoms of compression of retrosternal structures have been reported to occur in up to a third of cases with life threatening consequences[35]. Complications include brachial plexus and vascular injuries, oesophageal ruptures and tracheal compression and there have been 5 known reported cases of deaths[2].

Untreated anterior dislocations will result in a longstanding cosmetic deformity, which some patients may find unsightly. Persistent pain and instability are the main reasons for failure of surgical stabilisation of SCJ injuries[8].

THE FLOATING CLAVICLE

Dislocation of SCJ does not always occur in isolation and may occur in combination with the ACJ. This is known as bipolar clavicular dislocation or the traumatic floating clavicle. Only 40 cases have been described in the literature making this injury rare[13]. The first case was described by Porral[36] in 1831 and since then there has been intermittent reports of this injury, which in the majority of cases is due to high velocity road traffic collisions, falls from height and heavy objects falling onto the shoulder. Management of this injury should be designed on an individual patient basis. All reported an anterior dislocation of the SCJ and posterior dislocation of the ACJ.

More recently the first ever-case report of floating clavicle with a unique combination of posterior SCJ dislocation with Grade Ⅲ ACJ dislocation was reported. The authors had recommended surgical stabilisation of both SCJ and the ACJ for this injury[37].

CONCLUSION

Dislocations of the SCJ are rare and may result from direct trauma as an acute occurrence or in the more persistent case of atraumatic structural instability or non structural abnormal muscle patterning. Traumatic structural dislocation should be investigated appropriately with the use of CT if the diagnosis is unclear. The use of acute reduction of anterior dislocations is debatable as up to 100% re-dislocate and reduction techniques are not without risk. Posterior dislocations with compressive symptoms need to be reduced promptly to prevent life threatening complications. Persistent pain and instability can be managed surgically through a variety of means. Surgical stabilisation using braided polyester weave device (Surgilig Lockdown) has shown promising results in the functional outcome studies that I have been involved in. The use of pin transfixation however is absolutely contraindicated due to the high risk of pin migration and death.

Surgical management of SCJ injuries are technically demanding. The surgeon should be familiar with the complex anatomy and it is recommended that these procedures be carried out in large centres with cardiothoracic surgical back up if required to deal with any intra operative or post operative complications.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Promising short-term clinical results of the cementless Oxford phase III medial unicondylar knee prosthesis

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Abstract

AIM: To investigate the short-term clinical results of the Oxford phase III cementless medial unicondylar knee prosthesis (UKP) compared to the cemented medial UKP.

METHODS: We conducted a cross-sectional study in a tertairy orthopedic centre between the period of May 2010 and September 2012. We included 99 medial UKP in 97 patients and of these UKP, 53 were cemented and 46 were cementless. Clinical outcome was measured using a questionnaire, containing a visual analogue scale (VAS) for pain, Oxford Knee score, Kujala score and SF-12 score. Knee function was tested using the American Knee Society score. Complications, reoperations and revisions were recorded. Statistical significance was defined as a *P* value < 0.05.

RESULTS: In a mean follow-up time of 19.5 mo, three cemented medial UKP were revised to a total knee prosthesis. Reasons for revision were malrotation of the tibial component, aseptic loosening of the tibial component and progression of osteoarthritis in the lateral- and patellofemoral compartment. In five patients a successful reoperation was performed, because of impingement or (sub)luxation of the polyethylene bearing. Patients with a reoperation were significant younger than patients in the primary group (56.7 *vs* 64.0, *P* = 0.01) and were more likely to be male (85.7% *vs* 38.8%, *P* = 0.015). Overall the cementless medial UKP seems to perform better, but the differences in clinical outcome are not significant; a VAS pain score of 7.4 *vs* 11.7 (*P* = 0.22), an Oxford Knee score of 43.3 *vs* 41.7 (*P* = 0.27) and a Kujala score of 79.6 *vs* 78.0 (*P* = 0.63). The American Knee Society scores were slightly better in the cementless group with 94.5 *vs* 90.2 (*P* = 0.055) for the objective score and 91.2 *vs* 87.8 (*P* = 0.25) for the subjective score.

CONCLUSION: The cementless Oxford phase III medial UKP shows good short-term clinical results, when used in a specialist clinic by an experienced surgeon.

Key words: Knee osteoarthritis; Unicondylar knee arthroplasty; Cementless; Treatment outcome; Reoperation

Core tip: The higher revision rate in unicondylar knee arthroplasty compared to total knee arthroplasty is a concern. The cementless unicondylar knee prosthesis (UKP) eliminates one of the technical errors related to failure; the cementing technique. The cementless Oxford UKP also shows reduced radiolucent lines at one year follow-up, whereas the cemented UKP shows occurrence of radiolucent lines. The developing hospital has published encouraging results of the cementless Oxford phase III medial UKP. In our independent retrospective cohort study we observed three revisions of cemented UKP. There were five successful reoperations. The cementless UKP seems to perform better, but no significant difference could be found.

van Dorp KB, Breugem SJM, Bruijn DJ, Driessen MJM. Promising short-term clinical results of the cementless Oxford phase III medial unicondylar knee prosthesis. *World J Orthop* 2016; 7(4): 251-257 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i4/251.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i4.251

INTRODUCTION

The unicondylar knee prosthesis (UKP) is an established treatment for end-stage medial osteoarthritis (OA) of the knee and accounts for around 8%-10% of all primary knee replacements[1,2]. One of the successful implants used, is the cemented Oxford medial UKP phase III. This is a fully congruent mobile bearing prosthesis, which is implanted *via* a minimal invasive procedure with minimal bone-loss. Success of the medial UKP is still largely related to the indication for UKP and the experience of the surgeon and the surgical team. This is confirmed by the lower survival rates of UKP in national registers compared to the survival rates of UKP implanted by specialized surgeons who perform UKP surgery regularly[1,2].

The higher revision rates in unicondylar arthroplasty are a concern. The difference in revision rate between UKP and total knee prosthesis (TKP) is likely to be multi-factorial. A major issue seems to be the ease to choose for revision of a UKP compared to a revision of a TKP. With the introduction of the cementless Oxford UKP (2003) one of the technical errors related to failure, the cementing technique, can be eliminated. Also, the cementless Oxford medial UKP shows reduced radiolucent lines at one year follow-up, whereas the cemented Oxford medial UKP shows occurrence of radiolucent lines during follow-up[3]. The occurrence of these radiolucent lines is thought to be a misleading factor for revision in patients with unexplained pain after cemented UKP. The developing hospital has published encouraging results of the cementless Oxford phase III UKP[3], as well as cementless UKP by other manufacturers[4-6].

Since May 2010 the cementless Oxford phase III medial UKP is frequently used in our clinic besides the cemented Oxford phase III medial UKP. In accordance with earlier published results, it is our experience that the cementless Oxford UKP performs as well as, or even better than the cemented Oxford UKP. With this retrospective study we want to compare the short-term clinical outcome of the cemented and the cementless Oxford phase III medial UKP performed in an independent center by one single surgeon.

MATERIALS AND METHODS

Population

We conducted a cross-sectional study in an orthopedic center, specialized in prosthesiology and sports medicine. Between May 19, 2010 and September 01, 2011 a total of 106 medial UKP were implanted in 103 patients with primary medial osteoarthritis. For inclusion, patients had to meet the Oxford selection criteria for UKP and had to have a minimum follow-up of one year. Age, activity status and former high tibial osteotomy were not considered contra-indications. Exclusion criteria were patients who had surgery on their lower extremities less than 6 mo ago, hybrid fixation, patients with insufficient comprehension of the Dutch language and patients living abroad.

Of the 103 eligible patients, two patients were deceased at the time of follow-up and one patient refused participation. Four patients did not meet the inclusion criteria and were excluded from the study. Reasons for exclusion were: living abroad (two cemented UKP), surgery on the lower extremities less than 6 mo ago and Multiple Sclerosis with progressive muscle weakness (cementless UKP). In total 99 UKP in 97 patients were included in the study. All study participants provided informed written consent prior to study enrollment. All study participants agreed with anonymous data sharing.

Technique

The medial Oxford phase III cemented and the cementless UKP are similar in design, except for the cylindrical main peg and a smaller anterior peg added posterior to the main peg in the cementless femoral component. Additionally, the cementless UKP has a hydroxyapatite coating with a porous titanium under-coating to stimulate bone adhesion.

Table 1 Patient characteristics

	Cemented $n = 53$	Cementless $n = 46$	*P* value
Age (yr)	64.6 ± 8.2	62.2 ± 6.7	0.12
Sex			0.471
Male	21 (39.6%)	21 (45.7%)	
Female	32 (60.4%)	25 (54.3%)	
ASA			0.497
1	15 (28.3%)	10 (21.7%)	
2	30 (56.6%)	31 (67.4%)	
3	8 (15.1%)	5 (10.9%)	
BMI (kg/m^2)	27.7 ± 4.1	29.0 ± 4.7	0.17
Follow-up (mo)	20.5 ± 3.9	18.3 ± 4.5	0.02
Ahlbäck grade medial joint space			0.442
0 (> 3 mm)	0 (0%)	1 (2.2%)	
1 (< 3 mm)	41 (77.4%)	33 (71.7%)	
2 (Obliteration)	10 (18.9%)	12 (26.1%)	
3 (Attrition < 5 mm)	2 (3.8%)	0	
Ahlbäck grade lateral joint space			0.129
0 (> 3 mm)	53 (100%)	45 (95.7%)	
1 (< 3 mm)	0	2 (4.3%)	
2 (Obliteration)	0	0	
3 (Attrition < 5 mm)	0	0	
Ahlbäck grade patellofemoral joint space			0.139
0 (> 3 mm)	29 (54.7%)	18 (39.1%)	
1 (< 3 mm)	23 (43.4%)	28 (60.9%)	
2 (Obliteration)	1 (1.9%)	0	
3 (Attrition < 5 mm)	0	0	

BMI: Body mass index.

All surgeries were performed by the senior author (MD), who performs more than 100 UKP per year. A short medial arthrotomy was used, followed by a thorough inspection of the knee to make the final decision. If the chondropathy was limited to the antero-medial tibia plateau, the lateral compartment had full thickness cartilage in the weight-bearing areas and the ligaments were intact, the knee was fit for an UKP. A tourniquet was used in all cases. The surgical technique was performed as described in the Oxford operative manual, but without intramedullary alignment of the femur component, as we believe this enlarges the risk of haemarthrosis.

Patients were told to start active knee flexion and extension as soon as possible. Post-operative pain management consisted of Acetaminophen, Diclofenac and an epidural patient controlled pain pump with Chirocaïn/Sufentanil in the first ± 24 h. Full weight-bearing with two elbow crutches was started the second post-operative day. Thrombosis prophylaxis consisted of Nadroparine and a compression stocking for a period of 6 wk. Patients who did not reach full extension or had trouble reaching 90 degrees flexion at discharge started with physical therapy immediately. All other patient started physical therapy 2 wk post-operative, to ensure adequate wound healing the first two weeks.

Clinical and radiological evaluation

Except for patients who had a revision and patients who had a reoperation less than 6 mo ago, all patients received a questionnaire consisting a visual analogue scale (VAS) for pain ranging from 0-100 (0 being no pain), the Oxford Knee score (OKS) scored from 48 to 0 with 48 being the best possible outcome[7], the Kujala anterior knee pain score scored from 100 to 0 with 100 being the best possible score[8] and the SF-12 health survey[9]. If questions were left blank we contacted patients by phone. For clinical outcome we used the American Knee Society score[10] (AKSS objective and subjective score both ranging from 0-100, with 100 being the best possible score) performed by the first author (Karin B van Dorp) or by one of the co-authors. Range of motion and alignment were measured with the patient in supine position and with a goniometer measuring in 5 degree increments.

Revision was defined as a case in which the femoral or tibial component had to be removed and cases which were planned for this procedure. Cases in which nettoyage and polyethylene (PE) meniscal replacement took place or cases which were planned for this procedure are defined as reoperation.

Conventional X-rays in anteroposterior and lateral view, taken pre-operative, the first day post-operative and one year post-operative were evaluated on osteoarthritis grade per compartment using the Ahlbäck[11] (scored from 1 to 5, focusing on narrowing/attrition) by the first author. Progression of osteoarthritis of the lateral or patellofemoral compartment was defined as a change in Ahlbäck score between the X-rays taken the first day-post-operative and one year post-operative.

Statistical analysis

Data were analyzed using SPSS 17 (IBM, New York, United States). Statistical significance was defined as a *P* value < 0.05. Scale variables were tested using the independent samples *t* test. Pearson's χ^2 test was used in case of nominal or ordinal variables.

RESULTS

Of the 99 medial UKP implanted, 53 (53.5%) were cemented UKP and 46 (46.5%) were cementless UKP. Patient characteristics are described in Table 1. The groups were well matched, except for a shorter follow-up time in the cementless group 18.3 mo *vs* 20.5 mo (*P* = 0.02). This difference was caused by the relatively low volume of cementless UKP implanted in the introduction period.

Reoperations and revisions

During a mean follow-up of 19.5 mo (range 12-33 mo, SD 4.3), seven patients were eligible for reoperation (7%) and three revisions tot TKP were performed (3%). An overview of reoperations and revisions is given in Table 2. The main reason for reoperation was bony or soft-tissue impingement in four cases (4.1%). In two cases (2.0%) subluxation of the meniscal bearing and in one case (1.0%) a 90 degrees rotation of the

Table 2 Reoperations, revisions and outcome

Type	Fixation	Operation performed	Indication	Survival (mo)	Gender	Age (yr)	ASA	BMI kg/m^2	OKS	AKSS O/S
Revision	C	TKP PS 5/5/15 mm	Malrotation tibial component	16	Male	50	1	30.0	-	-
Redo	CL	Nettoyage PE 5 to 8	Subluxation PE	19	Male	50	1	30.0	48	100/100
Revision	C	TKP elsewhere	Aseptic loosening tibial component	20	Female	78	1	27.2	-	-
Redo	C	Nettoyage PE 5 to 6	PE luxation 90 degrees	21	Male	60	2	32.8	46	100/100
Redo	CL	Nettoyage PE 5 to 7	Impingement	21	Male	55	3	32.4	37	80/90
Redo	CL	Nettoyage PE 4 to 7	Impingement	21	Male	64	2	31.7	42	90/100
Redo	C	Nettoyage PE 4 to 6	Subluxation PE	22	Male	51	2	28.4	48	95/100
Redo	CL	Planned	Impingement	23	Male	55	2	26.6	-	-
Redo	CL	Planned	Impingement	26	Female	62	2	25.8	-	-
Revision	C	ACS 5/5/12, 5 mm	Progression of OA lateral/PF	27	Male	51	2	36.3	-	-

BMI: Body mass index; OA: Osteoarthritis; C: Cemented; CL: Cementless; PE: Polyethylene meniscus; OKS: Oxford knee score; AKSS O/S: American knee society score objective score/subjective score.

meniscal bearing occurred. Reoperations were treated with a minimal invasive medial arthrotomy, using the old incision. The impinging osteophytes were removed with a small osteotome, the presence of posterior osteophytes was checked with a curved osteotome and excessive fibrotic tissue was removed. In all cases a thicker PE meniscus was necessary to gain the appropriate balance. The clinical outcome of the reoperations, which were performed more than 6 mo ago, were all good to excellent (Table 2). Statistically, patients with a reoperation were significant younger than patients in the primary group (56.7 *vs* 64.0, *P* = 0.01) and were more likely to be male (85.7% *vs* 38.8%, *P* = 0.015). There were no significant differences between the primary group and the redo group concerning body mass index (BMI), ASA classification, SF-12 scores and pre-operative or post-operative OA grade.

All three revisions (3.1%) to TKP were cemented Oxford UKP. Reasons for revision were malrotation of the tibial component, aseptic loosening of the tibial component (revision surgery was performed elsewhere) and progression of OA in the lateral- and patellofemoral compartment. The time to revision was 16, 20 and 27 wk post-implantation. There were no significant differences between the primary group and the revision group concerning age, gender, BMI, ASA classification, SF-12 scores and pre-operative or post-operative Ahlbäck score.

Functional outcome

The revisions and reoperations excluded, 89 of the original UKP were still *in situ* and eligible for clinical assessment. Although no significant differences were found, the scores were slightly better in the cementless group, with a VAS pain score of 7.4 *vs* 11.7 (*P* = 0.22), an OKS of 43.3 *vs* 41.7 (*P* = 0.27) and a Kujala score of 79.6 *vs* 78.0 (*P* = 0.63) (Figure 1).

Because of health issues three patients accounting for four medial UKP were not able to come to our clinic for clinical evaluation. One patient refused clinical evaluation because of personal reasons. All these patients had good to excellent OKS outcomes (48, 48, 48 and 38). Of the remaining 85 medial UKP, 44 UKP (51.2%) were cemented and 41 (48.8%) were cementless UKP. The AKSS scores were slightly better in the cementless group 94.5 *vs* 90.2 (*P* = 0.055) for the objective score and 91.2 *vs* 87.8 (*P* = 0.25) for the subjective score, both not significantly different (Figure 1). The SF-12 scores were not significantly different in the cementless group, with a mean Physical Component Summary (PCS) score of 49.5 *vs* 47.6 (*P* = 0.28) and Mental Component Summary (MCS) score of 55.3 *vs* 54.5 (*P* = 0.60).

Complications

There were no cases of thrombosis or deep infection. No vascular or neurological complications occurred. No fractures were observed post-operatively in this cohort. One patient experienced a length difference of the operated leg after a total hip replacement, which resulted in an inappropriate gait pattern and led to pain in the knee in which the medial UKP was implanted (VAS score 76, OKS 9, Kujala 26).

DISCUSSION

With this cross-sectional study we wanted to compare the short-term clinical outcomes of the cemented and the cementless Oxford phase Ⅲ medial UKP performed

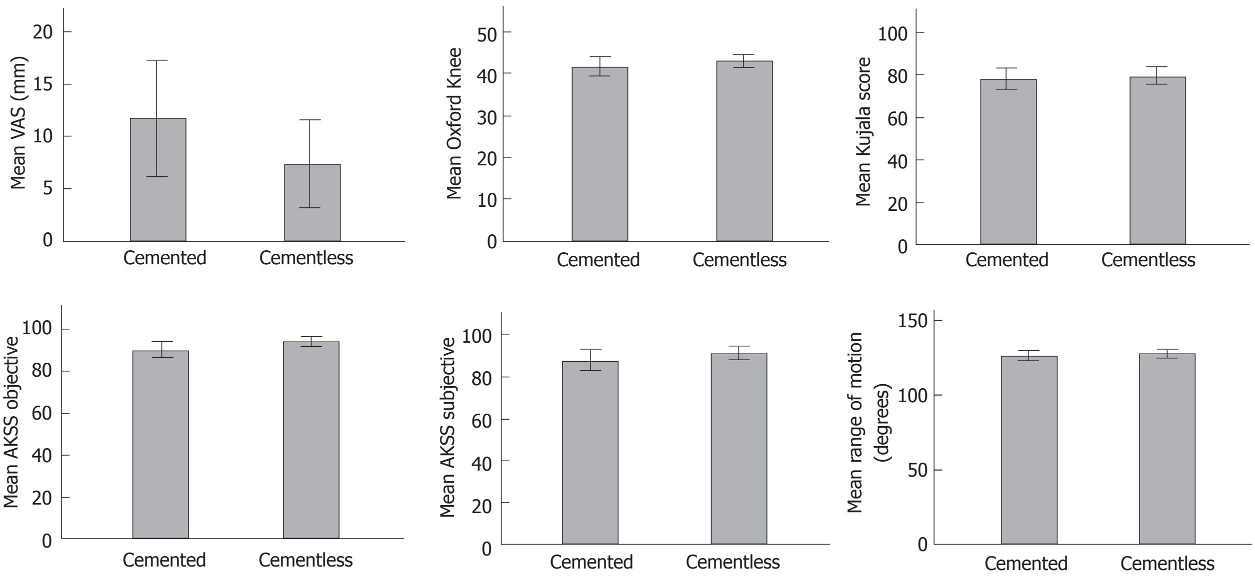

Figure 1 Questionnaire and clinical outcome (mean score with 95%CI error bars).

in an independent center by one single surgeon. We achieved a good to excellent short-term clinical outcome of both the cemented and the cementless Oxford UKP. Although not significant different, the cementless UKP showed better clinical results compared to the cemented UKP. These results support the good clinical results of the Oxford study group[12,13].

In three cases (sub)luxation of the PE bearing occurred. PE bearing exchange with a good clinical outcome was not considered as a revision, but was listed as a reoperation (Table 2). In four cases the patient experienced impingement of the PE bearing, because of bony- or soft tissue re-growth at the bone ridge cranial to the anterior side of the femur condyle.

Patients requiring a reoperation were significantly younger and more frequently male. In earlier Oxford UKP survival studies gender has shown not to affect UKP survival. Whether age under 60 years old influences the survival rates is still a discussion. The Oxford group has shown in their studies no significant difference between survival in patients under and over 60 years old[13]. Worldwide registers and other independent studies however show higher revision rates in patients under 60 years old[14-16]. Patients aged under 60 in the reoperation group were relatively active patients, which we think might be part of the explanation for (sub)luxation. Impingement might be caused by too little bone resection cranial to the anterior side of the femur component or because of re-growth. We currently use the microplasty instrumentation and aim for a resection of approximately 10 mm caudal to the femur component, which seems to reduce the amount of patients with signs of anterior impingement.

Based on our results and experience, we believe that if there is an obvious reason for pain in a medial UKP, a reoperation can be successful and it prevents (early) revision surgery. This does require accurate patient selection, based on physical examination and radiologic reviewing by an experienced surgeon.

There were no revisions in the cementless group. Of the cemented UKP, three had to be revised to a TKP, two of these revisions were performed in our clinic. Reasons for revision were malposition, aseptic loosening of the tibia component and progression of OA in the lateral and patellofemoral compartments. The time to revision varied between 16-27 mo. Two of the revisions were performed within the first two years after implantation. Generally, it is not recommended to revise a medial UKP to a TKP in the first two years after implantation, because of tibial stress and the bone remodeling that occurs. In this phase, medial pain is common and a bone scintigraphy can show false-positive results. Unless there is an obvious reason for failure of the UKP, revision to a TKP in this phase can be unsatisfying[13].

The revision rates of the cemented UKP lie in between the excellent results of the Oxford study group[13] and the Joint registry reports[17].

Surgical errors play a considerable role in UKP failure, as over-correction of an existing valgus deformity, overstuffing and cementing technique are frequently reported reasons for revision[17]. With the cementless UKA, cementing errors such as uneven distribution of the cement, cement residue posterior and loose particles, are eliminated. It is also known that cemented medial UKP show physiological radiolucent lines at follow-up, a phenomenon that is less seen in the cementless medial UKP[3]. Physiological radiolucent lines after medial UKP can easily be mistaken for radiolucency due to aseptic loosening. These factors may contribute to lower revision rate in cementless medial UKP compared to cemented medial UKP[1].

The cementless UKP needs an adequate initial fixation. Although not observed in this cohort, periprosthetic tibia plateau fractures are more frequently observed in cementless UKP. This might be due to a deep posterior tibial cortical cut or due to hard hammering, both should be avoided.

The strength of this study is the specialized character of our clinic and the choice to only include patients operated by one single surgeon. The occurrence of surgical errors is related to the frequency of the operation performed and the experience of the surgeon and his staff[17]. Our clinic is specialized in sports-, arthroscopic- and prosthetic surgery. We perform approximately 200 UKP per year of which more than half are performed by the senior author (Marcel JM Driessen). By comparing the clinical outcome of the cemented and cementless UKP performed by a single surgeon, we eliminated a surgeon bias for indication as well as a bias in surgical technique. Limitations of this study are the cross-sectional design and the relatively short follow-up time.

The cementless Oxford phase Ⅲ medial UKP shows promising short-term clinical outcome when used in a specialized orthopedic center. Because of the promising results of the cementless Oxford phase Ⅲ medial UKP, it is now the most used medial UKP in our clinic for eligible patients.

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COMMENTS

Background

The unicondylar knee prosthesis (UKP) is an established treatment for end-stage osteoarthritis (OA) of the knee and accounts for around 8%-10% of all primary knee replacements. One of the successful implants used, is the cemented Oxford medial UKP phase III. This is a fully congruent mobile bearing prosthesis, which is implanted *via* a minimal invasive procedure with minimal bone-loss. The success of the medial UKP is still largely related to the indication for surgery and the experience of the surgeon and the surgical team. The higher revision rates in unicondylar arthroplasty are a concern. The difference in revision rate between a UKP and a total knee prosthesis (TKP) is likely to be multi-factorial. A major issue seems to be the ease of choosing for a revision of a UKP compared to a TKP.

Research frontiers

The developing hospital has published encouraging results of the cementless Oxford phase III medial UKP, as well has cementless UKP by other manufacturers.

Innovations and breakthroughs

With the introduction of the cementless Oxford UKP (2003) one of the technical errors related to failure, the cementing technique can be eliminated. Also, the cementless Oxford medial UKP shows reduced radiolucent lines at one year follow-up, whereas the cemented Oxford medial UKP shows occurrence of radiolucent lines during follow-up. The occurrence of radiolucent lines is thought to be a misleading factor for revision in patients with unexplained pain after cemented UKP. In accordance with earlier published results, it is our experience that the cementless Oxford UKP performs as well as, or even better than the cemented Oxford UKP.

Applications

With this retrospective study the authors want to compare the short-term clinical outcome of the cemented and the cementless Oxford phase III medial UKP performed in an independent center by one single surgeon.

Peer-review

This is a good article.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Ankle fracture configuration following treatment with and without arthroscopic-assisted reduction and fixation

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Author contributions: Angthong C designed and performed the research, analyzed the data and wrote the paper.

Institutional review board statement: This study (study code: MTU-EC-OT-0-099/54) was approved by the institutional review board of the Faculty of Medicine, Thammasat University, Pathum Thani, Thailand.

Informed consent statement: All involved participants gave their informed consent prior to study inclusion.

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Data sharing statement: The original dataset is available on request from the corresponding author at chatthara@yahoo.com.

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Abstract

AIM: To report ankle fracture configurations and bone quality following arthroscopic-assisted reduction and internal-fixation (ARIF) or open reduction and internal-fixation (ORIF).

METHODS: The patients of ARIF (n = 16) or ORIF (n = 29) to treat unstable ankle fracture between 2006 and 2014 were reviewed retrospectively. Baseline data, including age, sex, type of injury, immediate postoperative fracture configuration (assessed on X-rays and graded by widest gap and largest step-off of any intra-articular site), bone quality [assessed with bone mineral density (BMD) testing] and arthritic changes on X-rays following surgical treatments were recorded for each group.

RESULTS: Immediate-postoperative fracture configurations did not differ significantly between the ARIF and ORIF groups. There were anatomic alignments as 8 (50%) and 8 (27.6%) patients in ARIF and ORIF groups (P = 0.539) respectively. There were acceptable alignments as 12 (75%) and 17 (58.6%) patients in ARIF and ORIF groups (P = 0.341) respectively. The arthritic changes in follow-up period as at least 16 wk following the surgeries were shown as 6 (75%) and 10 (83.3%) patients in ARIF and ORIF groups (P = 0.300) respectively. Significantly more BMD tests were performed in patients aged > 60 years (P < 0.001), ARIF patients (P = 0.021), and female patients (P = 0.029). There was no significant difference in BMD test t scores between the two groups.

CONCLUSION: Ankle fracture configurations following

surgeries are similar between ARIF and ORIF groups, suggesting that ARIF is not superior to ORIF in treatment of unstable ankle fractures.

Key words: Arthroscopy; Ankle; Fractures; Fracture fixation; Bone densitometry reports

Core tip: There was no significant difference between arthroscopic-assisted reduction and internal-fixation (ARIF) and open reduction and internal-fixation (ORIF) in immediate-postoperative ankle fracture configuration in the present study. Although the use of arthroscopy in orthopaedic trauma is increasing, the effectiveness of ARIF compared with that of ORIF in the management of ankle fractures has yet to be verified. The low rate of bone mineral density testing reflects a lack of awareness of the need for routine post-injury testing for osteoporosis in patients with ankle fractures.

Angthong C. Ankle fracture configuration following treatment with and without arthroscopic-assisted reduction and fixation. *World J Orthop* 2016; 7(4): 258-264 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i4/258.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i4.258

INTRODUCTION

Ankle arthroscopy, introduced into the field of ankle surgery for several years is a minimally invasive intra-articular treatment with several advantages[1,2]. Miyamoto *et al*[3] reported the benefit of arthroscopic examination in the diagnosis of syndesmotic disruption, which occurs mostly with ankle fracture. Imade *et al*[4] also demonstrated the advantages of arthroscopic procedures for ankle injury combined with Maisonneuve fracture, such as arthroscopic-assisted visualization during syndesmotic screw fixation, and drilling an osteochondral lesion of the talus. Takao *et al*[5] proposed the role of arthroscopic-assisted reduction and internal fixation for accurate diagnose and treat intra-articular disorders combined with distal fibular fractures. However, there are no reports of fracture configuration and bone quality in patients with unstable ankle fractures treated with arthroscopic-assisted reduction and internal fixation (ARIF) *vs* open reduction and internal fixation (ORIF).

To address this, the immediate-postoperative configurations of intra-articular ankle fractures, as well as bone quality *via* postoperative bone mineral density (BMD) testing, were investigated in a series of unstable ankle fractures treated with ARIF or ORIF. Relationships between relevant patient and technical variables and postoperative BMD were also determined. The study tested the hypothesis that there was no difference between ARIF and ORIF; the alternative, that ARIF is superior to ORIF in the treatment of unstable ankle fracture, would be demonstrated by associations between ARIF and superior anatomic fracture configuration. A second aim of the study was to determine the prevalence of post-injury BMD testing in order to evaluate clinicians' level of awareness regarding the need for investigation of osteoporosis in patients with ankle fractures.

Table 1 Patients' baseline data

	Arthroscopic-assisted reduction and internal fixation	Open reduction and internal fixation	*P* value
Number	16	29	
Age (yr)[1]	47.8 ± 16.3	45.0 ± 16.8	0.590
Male/female	5/11	19/10	0.035[2]
Lauge-Hansen Supination/ pronation	14/2	19/10	0.164
Bone mineral density test	7 (43.8%)	3 (10.3%)	0.021[2]

[1]Mean ± SD; [2]Significant difference.

MATERIALS AND METHODS

The medical records of patients who underwent fixation of unstable ankle fractures between April 2006 and October 2014 were reviewed retrospectively. After the exclusion of patients with incomplete or unavailable medical records or inadequate radiographic data, 45 ankle fractures in 45 patients [mean age, 46.5 years (range, 18-80 years)] were included in the study. ARIF (n = 16) or ORIF (n = 29) had been performed at the discretion of the attending surgeon. Thirty-three patients (73.3%) had a supination-type[6] ankle fracture and 12 (26.7%) had pronation-type[6] ankle fracture. Baseline data, including demographic information, and the rate of BMD testing, are presented in Table 1. This study was approved by the institutional review board of the medical center where this study (study code: MTU-EC-OT-0-099/54) was performed.

Operative technique

Before each procedure, the operated limb was exsanguinated and a thigh tourniquet was inflated to 250-300 mmHg and deflated after wound closure. All patients in the ARIF group were operated on by the same foot-ankle arthroscopy fellowship-trained surgeon (CA). Fracture configuration was checked after fixation by fluoroscopic and arthroscopic examination and corrected, whenever possible, if the alignment was not acceptable. As recommended by Miyamoto *et al*[3], direct visualization *via* arthroscopy was achieved with the use of fluid irrigation *via* gravity flow (*i.e.*, without a pump), through the anterolateral and anteromedial portals. Arthroscopic assessment was performed after fixation in order to evaluate the stability of the distal

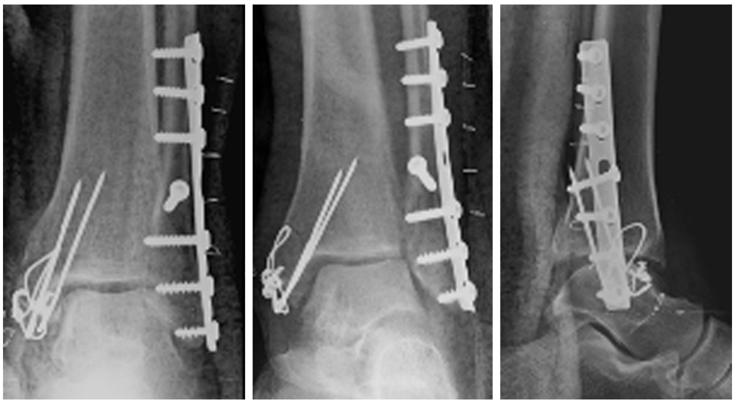

Figure 1 The immediate-postoperative fracture configuration *via* the radiograph in the arthroscopic-assisted reduction and internal fixation group.

tibiofibular syndesmosis, with fixation considered inadequate if an opening of 2 mm could be identified, and to identify and debride any fibrous tissue interposed in the distal tibiofibular joint. Any other intra-articular disorders, such as osteochondral injury and synovitis, which often accompany unstable ankle fracture, were accessed and treated at that time.

In the ORIF group, patients were operated on by the author, other orthopaedic trauma surgeons, or fellowship-trained foot-ankle surgeons. Anteromedial approach was used for medial malleolar reduction and fixation. The reduction was mainly confirmed by the apposition of fracture ridge at the outer rim of ankle joint and not the direct vision in the joint space. It was also confirmed by the fluoroscopic examination. Lateral approach was used for lateral malleolar or distal fibular reduction and fixation. The reduction was mainly confirmed by the apposition of fracture ridge at the outer rim of ankle joint and not the direct vision in the joint space. It was also confirmed by the fluoroscopic examination. The final configuration of fractures and alignments was checked by fluoroscopic examination after all fixation(s) and, if the alignment was not acceptable, corrected if possible. Surgical drains, including a drain set to bulb suction or a Penrose drain, were placed prior to closing the wound at the discretion of the attending surgeon. A posterior short leg splint was applied after wound closure in all cases.

Radiographic outcome

For all patients, independent evaluations of plain radiographs (anteroposterior, mortise, and lateral views) were conducted by trained orthopedic interns to determine immediate-postoperative fracture configuration and arthritic changes following the surgeries. Assessment of step-off and the widest gap at any intra-articular site of fracture involvement was graded according to the following scales: (1) Detailed evaluation of step-off/gap: Fracture configuration was considered anatomic for a step-off/gap of $\leqslant$ 1.0 mm, good for 1.1-2.0 mm, fair for 2.1-3.0 mm; and poor for > 3.0 mm); (2) General evaluation of step-off/gap: Fracture configuration was also assigned a general grade of either acceptable (step-off/gap $\leqslant$ 2.0 mm) or unacceptable (step-off/gap > 2.0 mm).

Statistical analysis

Data were analyzed using SPSS for Windows, Version 13.0 (SPSS Inc., Chicago, IL, United States). Categorical variables were compared using the Fisher's exact test or χ^2 test, and continuous variables were compared using Student's *t* test for normally distributed data or the Mann-Whitney *U* test for non-normally distributed data. A *P* value of < 0.05 was considered statistically significant.

RESULTS

Neither group demonstrated compartment syndrome or significant complications postoperatively. Table 1 presents a comparison of demographic and clinical variables between the ARIF and ORIF groups. The ARIF and ORIF groups did not differ significantly in age or fracture type (Lauge-Hansen supination/pronation[6]). However, there were significantly more female patients in the ARIF group than in the ORIF group (*P* = 0.035), and significantly more ARIF patients than ORIF patients underwent post-injury BMD testing (*P* = 0.021).

Table 2 presents radiographic outcomes for both groups. There was no significant difference in immediate-postoperative fracture configuration, as assessed by both detailed and general grading systems, between the ARIF (Figure 1) and ORIF (Figure 2) groups. Regarding the arthritic changes of ankle following the fracture, there were 20 patients who had the follow-up period as at least 16 wk following the surgeries (mean follow-up time: 9.8 mo; range 4-22 mo). There were 16 patients (80%) who had mild to significant level of arthritic changes (Table 3). In addition, there were no significant difference of the rates of arthritic changes between ARIF and ORIF groups (*P* = 0.3) (Table 3). Regarding the postoperative complications, there were two patients who had the available records reporting postoperative complications in overall study (ORIF group: 1 patient with major complications needing additional surgeries; ARIF group: 1 patient with a general complication

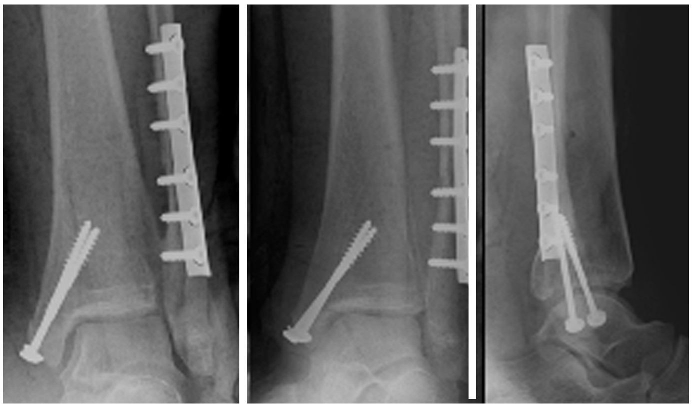

Figure 2 The immediate-postoperative fracture configuration *via* the radiograph in the open reduction and internal fixation group.

Table 2 Radiographic outcomes

	Arthroscopic-assisted reduction and internal fixation	Open reduction and internal fixation	*P* value
Meticulous grading			
Anatomic (step/gap ≤ 1.0 mm)	8 (50%)	8 (27.6%)	0.539
Good (step/gap = 1.1-2.0 mm)	4 (25%)	9 (31.0%)	
Fair (step/gap = 2.1-3.0 mm)	2 (12.5%)	5 (17.2%)	
Poor (step/gap > 3.0 mm)	2 (12.5%)	7 (24.1%)	
General grading			
Acceptable (step/gap ≤ 2.0 mm)	12 (75.0%)	17 (58.6%)	0.341
Unacceptable (step/gap > 2.0 mm)	4 (25.0%)	12 (41.4%)	

Table 3 Arthritic changes following the surgical treatments

Treatment groups	Arthritic changes[1]				
	None	Mild	Moderate	Significance	*P* value
Arthroscopic-assisted reduction and internal fixation	2 (25%)	3 (37.5%)	0	3 (37.5%)	0.3
Open reduction and internal fixation	2 (16.7%)	6 (50%)	3 (25%)	1 (8.3%)	
Total	4 (20%)	9 (45%)	3 (15%)	4 (20%)	

[1]Arthritic changes was described as mild (presence of osteophyte), moderate (narrowing of joint space), and significance (presence of osteophyte associated with narrowing of joint space).

with no need of additional surgeries). In ORIF group, a mentioned patient had major complications as malaligned fracture and loss of reduction following the initial surgery. In the retrospective review of his initially postoperative radiograph, there was the non-anatomic reduction of medial malleolar fracture with a fracture gap around 1.4 mm (Figure 3) but it was missed during the procedure. He also had the surgical wound inflammation and possible infection that needed the surgical debridement and hardware removal. He was treated with an ankle arthrodesis as a definitive procedure. He could return to recovery uneventfully following the final treatment. In ARIF group, a mentioned patient had a general complication as the surgical wound inflammation and possible infection that needed only intravenous antibiotic medication and local wound care. Her wound had been healed uneventfully following the mentioned treatment. Both major and general complications rates were no significant differences between the two groups ($P > 0.05$).

Table 4 compares demographic, clinical, and perioperative data for patients who did and did not undergo BMD testing. Of the 45 study patients, only 10 (22.2%) underwent post-injury BMD testing; 8 of 10 BMD-tested patients had a *t* score indicative of osteopenia[7,8]. There were significantly higher rates of BMD testing in patients aged > 60 years ($P < 0.001$), patients who underwent ARIF ($P = 0.021$), and female patients ($P = 0.029$). However, bone quality, as assessed by BMD-test *t* scores, did not differ significantly between the ARIF and ORIF groups. In addition, no significant difference was found in the prevalence of BMD testing between low- and high-energy-fractures ($P = 0.341$) or among the differences of postoperatively fracture configurations ($P = 0.06$).

Subgroup analysis of the arthroscopic findings of patients in the ARIF group is presented in Table 5. Osteochondral lesion of the tibial plafond (modified Outerbridge grade II[9]) was found in one patient. The most common locations of talar lesions were the anterolateral (37.6%) and anteromedial (18.8%) areas. Sixty percent of microfractures as described by previous authors[1] were performed for grade III-IV osteochondral lesions.

DISCUSSION

Over the past decade, the number of orthopedic surgical procedures performed with arthroscopic assistance has increased[3-5]. Indications for ARIF include transchondral talar dome fracture, talar fracture, low-grade fracture of the distal tibia, syndesmotic injury, malleolar fracture, and chronic pain following definitive management of fracture about the ankle[3-5,10]. Among

Table 4 Bone mineral density test and related parameters

	Patients with BMD tests (*n* = 10)	Patients without BMD tests (*n* = 35)	*P* value
Age (yr)[1]	64.2 ± 9.4	40.8 ± 14.3	< 0.001[2]
Male/female	2/8	22/13	0.029[2]
Lauge-Hansen Supination/pronation	9/1	24/11	0.246
ORIF/ARIF	3/7	26/9	0.021[2]

[1]Mean ± SD; [2]Significant difference. ARIF: Arthroscopic-assisted reduction and internal fixation; BMD: Bone mineral density; ORIF: Open reduction and internal fixation.

Table 5 Arthroscopic findings in arthroscopic-assisted reduction and internal fixation patients

Findings	Number of patients (%)
Osteochondral lesions	
Talus	10 (62.5%)
Tibial plafond	1 (6.3%)
Modified outerbridge classification (talar lesion)	
Grade I	1 (6.3%)
Grade II	4 (25%)
Grade III	3 (18.8%)
Grade IV	2 (12.5%)
Synovitis	15 (93.7%)
Lateral	1 (6.3%)
Medial and lateral	11 (68.8%)
Unspecified	3 (18.8%)
Ligamentous injury	
None	6 (37.5%)
AITFL	6 (37.5%)
AITFL-PITFL	2 (12.5%)
AITFL-Deep deltoid	2 (12.5%)

ARIF: Arthroscopic-assisted reduction and internal fixation; AITFL: Anteroinferior tibiofibular ligament; PTFL: Posteroinferior tibiofibular ligament.

Figure 3 The initially postoperative radiograph revealed the non-anatomic reduction of medial malleolar fracture with a fracture gap around 1.4 mm which was missed during the primary procedure in the open reduction and internal fixation group.

the potential benefits are less extensive exposure, preservation of blood supply, and improved visualization of the pathology. However, data regarding fracture configuration and bone quality in patients with unstable ankle fractures treated with and without ARIF have not been reported.

The present study demonstrates no significant difference in immediate-postoperative configuration or arthritic changes in a short-term follow-up period between groups. Other authors[5], however, have previously shown superior results in the ARIF group. With regard to between-group differences in postoperative fracture configuration, the discrepancy between our results and those of other authors[5] may have been the result of the small number of patients in the ARIF group in the present study. Future prospective studies that include larger numbers of patients with longer term of follow-up and in which clinical scores are recorded in conjunction with the evaluation of postoperative fracture configuration and arthritic changes are necessary to determine whether there is a significant association between ARIF and better postoperative outcomes. However, as an alternative to conventional osteosynthesis, ARIF can facilitate correct assessment of surgical reduction of complex fractures and allow visualization of non-anatomical reductions that would not otherwise be detected under fluoroscopy[11]. This may help to minimize surgical soft-tissue damage and wound extension during surgical reduction[11,12]. Moreover, intra-articular pathology and associated cartilaginous lesions, such as those detected in the present study, can be evaluated and treated as appropriate[11,13].

Regarding the comparison of advantages and disadvantages between ARIF and conventional osteosynthesis or ORIF, the advantages of ARIF were demonstrated as it could directly assess a reduction of an intra-articular fracture and this could provide more anatomic reduction than ORIF. In addition, this procedure was able to perform the debridement to remove the residual hematoma and synovitis debris that might cause pain and limitation of an ankle motion after fixation. It could perform the arthroscopic repair of concomitant injury such as osteochondral lesions[11,13]. Finally, it could also help the surgeon to evaluate syndesmotic widening from the syndesmotic injury during the arthroscopic examination[3] and following syndesmotic fixation if this injury was associated with an ankle fracture. The disadvantages of ARIF could be informed as it might considerably add the operative time by the surgeon with an inadequacy of arthroscopic skills. The longer time of operation might potentially lead to the swelling of surgical wound and compartment syndrome, particularly in some types of ankle fractures such as a Maisonneuve fracture[4]. On the other hand, the advantages of ORIF were explained, as this approach was familiar with any surgeons who had basic skills of the open reduction and fixation of fracture. There was no need of arthroscopic skills to perform this conventional approach. Therefore, this approach is more reproducibility than ARIF. In addition, it has low risk of the compartment syndrome following the operation.

However, the disadvantages of ORIF could be as the inability to directly confirm the anatomic reduction of fractures in the joint space. The reduction was routinely checked by the apposition of fracture ridge at the outer rim of ankle joint and by the fluoroscopic examination. These methods could miss some subtle malreduction of fracture in the joint[11] as shown in one patient in ORIF group in the present study. This approach could not perform directly debridement of the residual hematoma included another debris in the joint. It could not perform simultaneously repair of associated lesions, such as osteochondral lesions, or directly assess the syndesmotic widening during the procedure. Surgeons may have to consider these advantages and disadvantages of each approach when they have to make any decision for their patients.

In the present study, only 22.2% of patients received a post-injury BMD test. This suggests a lack of awareness of the need for routine post-injury testing for osteoporosis in ankle-fracture patients; particularly those over the age of 45 (mean age of patients in the present study was 46.5 years). This lack of awareness is consistent with the same parameter in overall low-or high energy fractures in a previous study[7]. No significant difference was found in the prevalence of BMD testing between patients with low and high-energy fractures (P = 0.341) or among the grades of postoperative fracture configuration (P = 0.06). However, age > 60 years and female sex were identified in the present study to be factors significantly associated with post-fracture BMD testing. In ARIF patients, in-patient care by a single foot-ankle surgeon was a significant predictor of post-fracture BMD. Castel *et al*[14] proposed that many physicians do not recognize osteoporosis as a metabolic condition and thus fail to correlate it with other medical conditions. Suarez-Almazor *et al*[15] revealed that physician attitudes were vital factors in decisions about screening and treatment of osteoporosis. Female patients were more likely than male patients to receive BMD testing after a low-energy fracture[7]. Castel *et al*[14] proposed that this bias might be due to the misapprehension that osteoporosis is a problem affecting only females. Improved communication between orthopedic surgeons, specialists, and involved physicians with respect to evidence-based medicine may help to reduce the gap between fracture occurrence and osteoporosis management in both sexes.

In the present study, eight patients in a subgroup of 10 BMD-tested patients had t scores indicative of osteopenia[4,5]. It has been suggested that there is an association between vitamin D deficiency and osteoporosis[16]. The high rate of osteopenia in the present study is consistent with that of a previous study, which demonstrated vitamin D deficiency to be common among patients with foot or ankle fracture[17]. These studies highlight the importance of diagnosing osteoporosis in patients with ankle fractures, particularly in patients who have low energy fractures, in order to prevent subsequent fractures[18,19]. A limitation of the present study was that the small number of patients in the ARIF group might have made a between-group difference difficult to detect.

In conclusion, there was no significant difference between ARIF and ORIF in immediate-postoperative ankle fracture configuration or arthritic changes in a short-term follow-up period. Further study with larger number of patients and longer term of follow-up was needed to validate this conclusion. Although the use of arthroscopy in trauma is increasing, the effectiveness of ARIF compared with that of ORIF in the management of ankle fractures has yet to be verified. The low rate of BMD testing reflects a lack of awareness of the need for routine post-injury testing for osteoporosis in patients with ankle fractures.

ACKNOWLEDGMENTS

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COMMENTS

Background

Ankle arthroscopy, introduced into the field of ankle surgery for several years is a minimally invasive intra-articular treatment with several advantages. However, there are no reports of fracture configuration, bone quality, arthritic changes in patients with unstable ankle fractures treated with arthroscopic-assisted reduction and internal fixation (ARIF) *vs* open reduction and internal fixation (ORIF).

Research frontiers

The present study is to report ankle fracture configurations, bone quality, and arthritic changes following ARIF or ORIF.

Innovations and breakthroughs

In the past, some concerns arose about safety and efficacy of ARIF. In addition, some surgeons may concern it as difficult to perform for the routinely practice basis. The present study shows that ARIF is comparable to ORIF in terms of postoperative results as immediate-postoperative ankle fracture configuration or arthritic changes or complication rates in a short-term follow-up period. However, ARIF could directly assess a reduction of an intra-articular fracture or syndesmosis and this may provide more anatomic reduction than ORIF in larger study. In addition, arthroscopic treatments for associated intra-articular lesions can be performed in patients with ARIF. This kind of procedure is the advantage in the ARIF group.

Applications

Patients with unstable ankle fractures will benefit from ARIF, if treated with cautiously systematic steps as described in the section of operative technique, avoiding untreated intra-articular lesions which commonly associated with ankle fracture and possibly correlated with long term posttraumatic arthritis.

Terminology

ARIF is referred to the operation that uses an arthroscopic examination to evaluate the stability of the distal tibiofibular syndesmosis, fracture alignment following open reduction and internal fixation, and other intra-articular disorders, such as osteochondral injury and synovitis, which often accompany unstable ankle fracture. The improper alignment of fracture and associated intra-articular lesions can be accessed and treated at that time. ORIF is referred to the conventional operation that uses an open surgery to perform the fracture reduction and internal fixation. This kind of procedure does not include the arthroscopic examination during the procedure. Bone mineral density (BMD) testing is to measure how much calcium and other types of minerals are in a location of bone in each patient. This test helps the health care provider detect osteopenia or osteoporosis and predict the risk of fractures in each patient. The present study used a dual-energy X-ray absorptiometry scan for the BMD-test which would demonstrate the result in a value of "*t* score".

Peer-review

It is a well written article and very interesting.

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ORIGINAL ARTICLE

Retrospective Study

Use of Ligament Advanced Reinforcement System tube in stabilization of proximal humeral endoprostheses

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Author contributions: Stavropoulos NA and Turcotte RE designed the study; Stavropoulos NA, Sawan H and Turcotte RE analysed the literature; Stavropoulos NA, Sawan H and Dandachli F acquired and analyzed the data; Turcotte RE supervised the project and critically reviewed the draft; all authors approved the final submitted version of the manuscript.

Institutional review board statement: We are pleased to inform you that request has been found ethically acceptable and we hereby grant you approval, *via* expedited review by the Chairman on August 9, 2013, to conduct the aforementioned study at the McGill University Health Centre.

Informed consent statement: As per our regulations no informed consent is required to perform a retrospective review analysis of medical records and X-rays. Personal informations were kept confidential.

Conflict-of-interest statement: All authors declare that they have no conflict of interest. No benefits of any source were received for the production of this work.

Data sharing statement: As per our regulations no data sharing statement is required to perform a retrospective review analysis of medical records and X-rays. Personal informations were kept confidential.

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Abstract

AIM: To review outcomes following usage of the Ligament Advanced Reinforcement System (LARS®) in shoulder tumors.

METHODS: Medical records of nineteen patients (19 shoulders) that underwent tumor excisional procedure and reconstruction with the LARS synthetic fabric, were retrospectively reviewed.

RESULTS: Patients' median age was 58 years old, while the median length of resection was 110 mm (range 60-210 mm). Compared to immediate post-operative radiographs, the prosthesis mean end-point position migrated superiorly at a mean follow up period of 26 mo (P = 0.002). No statistical significant correlations between the prosthesis head size (P = 0.87); the implant stem body length (P = 0.949); and the length of resection (P = 0.125) with the position of the head, were found at last follow up. Two cases of radiological dislocation were noted but only one was clinically symptomatic. A minor superficial wound dehiscence, healed without surgery, occurred. There was no evidence of aseptic loosening either, and no prosthetic failure.

CONCLUSION: LARS® use ensured stability of the shoulder following endoprosthetic reconstruction in most patients.

Key words: Proximal humeral endoprostheses; Ligament Advanced Reinforcement System

Core tip: Endoprosthetic replacement of the proximal humerus for tumor resection offers predictable outcome. In an attempt to optimize functional scores, the use of Ligament Advanced Reinforcement System (LARS) tubes was facilitated. Our retrospective analysis revealed that LARS was not associated with specific complications. Its ability to ensure shoulder stability was good, albeit not perfect. Superior migration of the humeral head was common over time.

Stavropoulos NA, Sawan H, Dandachli F, Turcotte RE. Use of Ligament Advanced Reinforcement System tube in stabilization of proximal humeral endoprostheses. *World J Orthop* 2016; 7(4): 265-271 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i4/265.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i4.265

INTRODUCTION

Latest advances in the diagnosis and management of neoplastic diseases, conferring prolonged life expectancy, have resulted in limb-salvage surgery as the main treatment choice for patients with bone and soft tissues sarcomas[1-4]. Endoprostheses use has increased over the last 30 years with the overall 5-year survival rate rising from 20% to 85%[1,3,5].

The upper extremity neoplasms are a third less common than lower extremity ones[6]. Metastatic Bone Disease (MBD) is the most common cause of destructive bone lesions in adults, with the humerus as the second most common site, following the femur[7-9]. The proximal humerus (PH) is also the third most common region for osteosarcoma[6]. Even though limb-sparing surgery is the treatment of choice for 95% of tumors of the shoulder girdle, significant functional loss may follow[10]. Since the first reported operation, a partial scapulectomy for an aneurysmal tumor of the subscapular artery performed by Liston[11] in 1819, many surgical techniques have been described. Tumors of the PH should always meet the following values: (1) oncological principles of resection; (2) reconstruction of the missing segment; and (3) soft tissue reconstruction[10]. The success of any technique is established upon the ability to achieve a long disease-free survival, and a stable and functional shoulder joint. This may be impeded by complications such as aseptic or septic loosening, infection and mechanical failure[11,12]. Recently, a new classification of these complications has been proposed with soft tissue and joint instability referred to as Type 1 failure[13]. An unstable joint may lead to pain, discomfort, distress and inability to benefit from maximal usage of the hand and elbow. Stability relies primarily on the soft tissue envelope which includes: Labrum, joint capsule, rotator cuff and surrounding muscles. Maintaining joint stability can be rather challenging after the extensive resection of these structures, and albeit fundamental, ability to reattach soft tissues to the implant remains limited[13-15]. Although various implant suspension methods using tapes, wires or tendons have been described[16-21], the incidence of instability or dislocation has rarely been studied.

Capsuloplasty is achieved through reconstruction of the shoulder capsule with synthetic or collagenic tissue to secure stability. A previous study reported a 4.3% incidence of cranial subluxation of the proximal or total humerus prosthesis with synthetic Trevira® use[2]. The Ligament Advanced Reinforcement System (LARS®, Arc-sur-Tille, France), an artificial fabric made of polyethylene terephthalate, presents a great capacity for cellular and connective tissue properties both in the *in vitro* and *in vivo* studies[22,23]. It has been used mainly for knee ligament augmentation or replacement[24-27]. Our purpose was to report the results of the LARS® tube in the stabilization of proximal humeral endoprosthetic replacement for tumors, and to categorize any potential risk associated with its use.

MATERIALS AND METHODS

We retrospectively reviewed the medical records of 19 consecutive patients who underwent proximal humeral replacement, either due to sarcoma or to metastatic disease, followed by soft tissue reconstruction with LARS® synthetic fabric (LARS, Arc sur Tille, France). All procedures were performed by a single surgeon (RT). Implants were all Modular Replacement System of PH (MRS PH) (Stryker Orthopaedics Kalamazoo, Michigan, United States) (Figure 1). Extra articular resection was performed in one case only. Patients were operated through a standard deltopectoral approach with en bloc resection of the biopsy tract when applicable. According to the length of resection and soft tissue invasion, muscles and tendons were excised or detached from their bony attachment. Resection of the deltoid muscle may have differed based on the primary diagnosis. Joint capsule and rotator cuff tendons were sectioned at joint line level, and the labrum was preserved in all intra-articular resections. The axillary nerve was sacrificed in 2 cases. Surgical margins were assessed intraoperatively by pathologists. Reaming of the humeral medullary canal was performed and stem size was selected based on line to line sizing (French paradox)[21,28]. Implants were selected with respect to the length of resection and the humeral head size,

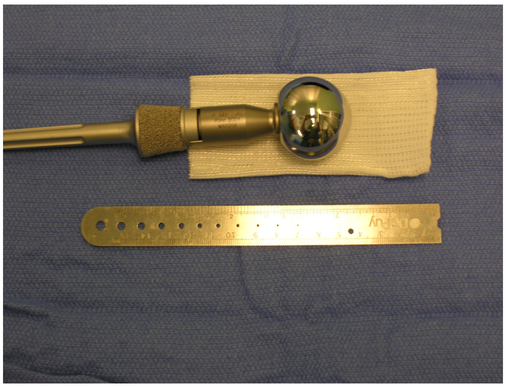

Figure 1 The prosthesis used was the Modular Replacement System of Proximal Humerus (Stryker Orthopaedics Kalamazoo, Michigan, United States).

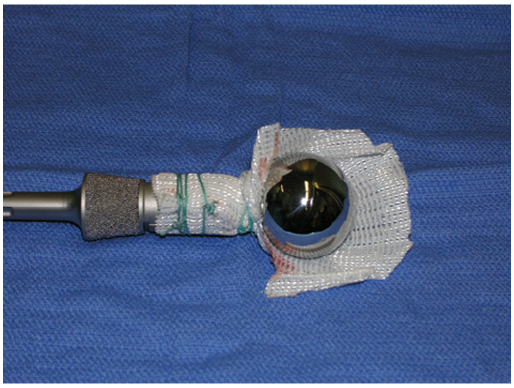

Figure 2 Proper preparation of the Ligament Advanced Reinforcement System tubing that was cut the appropriate length to properly cover the head and body but short of covering the porous surface of the implant immediately adjacent to the host humerus.

Table 1 Classification of humerus head implant position

1 > 50% inferior migration of Prosthesis H.Head
2 < 50% inferior migration of Prosthesis H.Head
3 = Centralized
4 < 50% superior migration of Prosthesis H.Head
5 > 50% superior migration of Prosthesis H.Head
6 = Unstable

either 40 or 44 mm. Proper cementation of the definitive construct was then performed ensuring the expected 40-45 degrees of retroversion of the head. The LARS® tube was cut the appropriate length to properly cover the head and body but short of covering the porous surface of the implant immediately adjacent to the host humerus (Figure 2). The fabric was secured to the implant with #5 Ethibond® sutures. The proximal end of the tube fabric was spitted open allowing suturing to the remaining glenoid capsule and labrum in a circumferential manner figure of eight with #2 Ethibond® sutures (Figures 3 and 4). This usually led to an initial passive range of motion approximating 50 degrees of abduction and flexion and 40 degrees of internal and external rotation. No anchors were used. Shoulder stability was evaluated by pulling the arm longitudinally from the scapula and found stable in all directions. Severed tendons and muscles were reattached to the fabric with non resorbable sutures when possible. Postoperatively, the upper extremity was left into an arm and cuff sling for 6 wk, to allow for scarring, after which it was discarded. Active and passive ranging of the elbow and hand was encouraged right after surgery. Particular attention was paid to the stability of the implant and the existence of any identifiable adverse effect of the LARS fabric. Digitized radiographs were obtained with patient in standing position and without any arm support.

Two independent reviewers performed a double-blind evaluation of the Anteroposterior (AP) views of the digitized radiographs. An object of known size was used as a marker to identify any magnification error. In order to evaluate the position of the prosthesis and the glenohumeral translation in the follow-up period, the percentage of the prosthesis head in correlation with the glenoid center, and with the superior and inferior glenoid rims, was assessed (Figure 5). The difference in distances between the midline from the glenoid center, and the midline from the center of the head of the prosthesis, was estimated and classified as shown in Table 1. Additionally, shoulder stability was evaluated by reviewing clinical notes. Functional assessment was based on the 1987 Musculoskeletal Tumor Society functional scoring system (MSTS)[29] collected prospectively preoperatively and at 3, 6, 12, 24 and 36 mo after surgery[29]. The analysis was performed by means of statistical software package (IBM SPSS v.19.0) statistical package. This study was approved by the hospital ethics committee. Study comprised 19 shoulders from 19 patients that underwent endoprosthetic replacement of the proximal humerus. Bone sarcoma made for 10 cases and metastatic disease for 9.

RESULTS

Ten patients were male. The median age was 58 years old (range: 23 to 77 years). Fifteen patients were right handed, three were left handed and one described himself as ambidextrous. Resection involved the right side in only 10 patients. Two thirds of cases (68%) presented with pathological fractures, and four patients had received neoadjuvant and adjuvant chemotherapy. Patients' characteristics are listed in Table 2. Following appropriate and individualized oncological pre-operative management, they underwent proximal humeral replacement and soft tissue reconstruction using the LARS synthetic fabric. The median length of resection was 110 mm (range 60-210 mm). The median humerus head size was 44 mm (range 35-50 mm), however, in 2 cases head size could not be measured due to the extent of bony destruction. In 9 patients the 40 mm modular head implant was selected and the rest received the 44 mm prosthesis. The implant body median length was 60 mm (range 40-140 mm). Utilizing the LARS

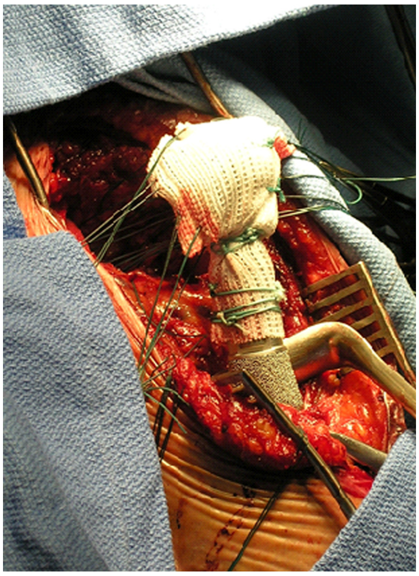

Figure 3 Suturing the remaining glenoid capsule and labrum with the proximal end of the fabric.

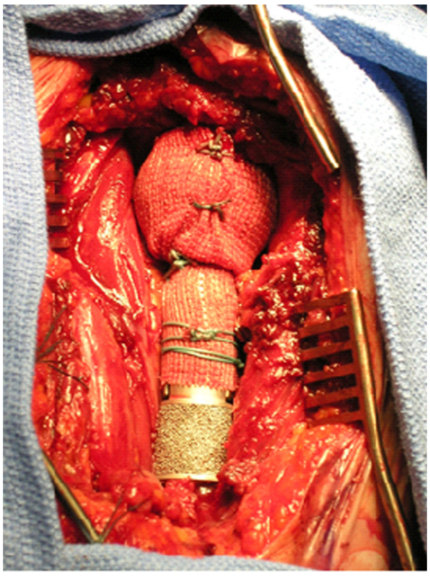

Figure 4 Final position of the proximal humeral endoprostheses.

Table 2 Patients characteristics

Patient	Sex	Age	Diagnosis	Lesion side
1	Male	43	Ewing sarcoma	R
2	Male	58	Telangiectatic osteogenic sarcoma	R
3	Female	31	Chondrosarcoma	L
4	Female	53	Metastatic carcinoma renal cell primary	R
5	Male	67	Metastatic lung primary	L
6	Female	51	Metastatic lung primary adenocarcinoma	R
7	Male	64	Chondrosarcoma	L
8	Female	63	Metastatic thyroid	L
9	Female	52	Chondrosarcoma	R
10	Female	64	Metastatic clear cell renal	L
11	Male	23	Ewing sarcoma	L
12	Male	54	Metastatic renal cell carcinoma	R
13	Female	61	Metastatic breast	R
14	Male	70	Metastatic renal	L
15	Female	51	Metastatic undiferentiated sarcoma of bone	L
16	Female	68	Chondrosarcoma	L
17	Male	66	Metastatic clear cell renal	R
18	Male	77	Metastatic lung adenocarcinoma	R
19	Male	52	Multiple myeloma	R

L: Left; R: Right.

tube allowed the deltoid to be reattached in 9 patients and the pectoralis major and long head of the biceps (or what was left of it) in 8 patients. Primary closure was achieved for all patients with no need for flap mobilization. No significant neurological deficit affecting elbow and hand function was identified. No local recurrence was detected as per clinical examination and radiological evaluation. Although mechanical loosening was not found, one patient complained of discomfort relating to gross instability. No identifiable adverse local tissue reactions were noted and there was no sign of delayed wound healing, even in patients who had undergone preoperative radiotherapy. A single case of minor superficial wound dehiscence, requiring minor care, occurred in the perioperative period. Radiological follow-up ranged from 14 to 2400 d (mean = 418 d). The overall follow-up period ranged from 14 to 2400 d (mean = 806 d).

Based on the proposed classification for head positioning with respect to the glenoid, statistical analysis revealed a mean post-operative starting position of 2.63 (from 3 = centralized head in the glenoid). The prosthesis mean final position was 3.68 (as 4 means < 50% superior migration). The prosthesis mean end-position tended to migrate more superiorly, at a mean follow up period of 26 mo (P = 0.002) (Figure 6). Inter observer reliability with respect to interpretation of the radiographs was very strong (kappa = 0.929 P < 0.01), thus, strength of agreement was almost perfect according to the Landis and Koch criteria[30]. During the follow up period, 2 prostheses were considered radiographically dislocated, but only one was symptomatically unstable and dislocated, requiring further surgical stabilization. No statistical significant correlation was found between the head size of the prosthesis used (P = 0.87); the size of the implant stem body height (P = 0.949); the length of resection (P = 0.125), and the position of the head at last follow up.

The functional results were described based on the functional rating system of the Musculoskeletal Tumor Society and the Toronto Extremity Salvage Score (TESS)[29,31,32]. Mean preoperative MSTS and TESS scores were 15.2 and 62.9, while the postoperative mean scores were 15.5 and 65 respectively. There was no correlation between preoperative MSTS score and end-function.

DISCUSSION

Endoprosthetic replacement of the PH offers a pre-

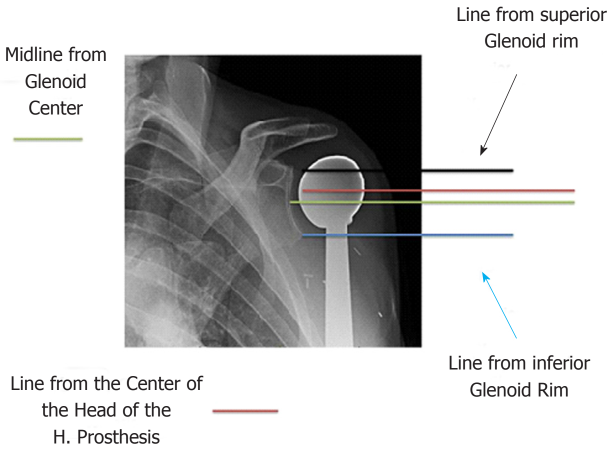

Figure 5 Radiological assessment of humerus head implant position.

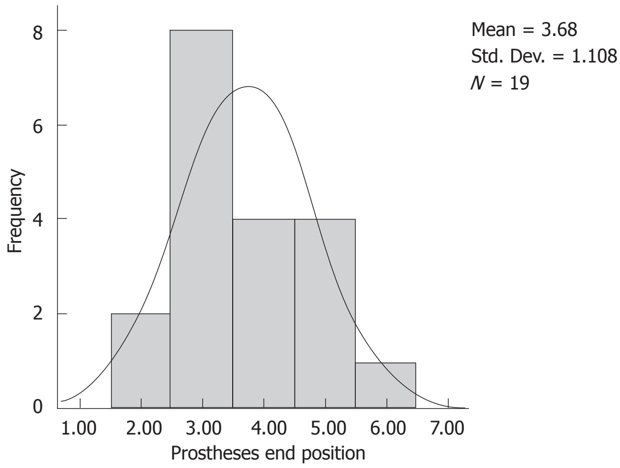

Figure 6 Prostheses end position.

dictable outcome, with acceptable cosmetic and complication rates, albeit the functional results are limited by the lack of active mobility and strength. It is a durable construct however, stability remains a challenge.

Since the first endoprosthetic PH replacement by Pean in 1893, with a platinum and rubber alloy implant, many different procedures have been described[33]. Sacrificing the rotator cuff and the deltoid in favor of oncological wider margins, and symptomatic instability with painful impingement on the subacromial arch, have been challenging potential complications[15]. Several authors have advocated capsuloplasty, using a mesh-like fabric aiming at providing a more stable prosthesis by fixing the prosthesis to the glenoid, and allowing the reattachment of the surrounding muscles and tendons[16,34,35]. Capsuloplasty, using Dacron aortic graft and Trevira Tubes, has been studied and reports support its usage[34]. The common features that characterize these fabrics are biocompatibility and porosity that encourage tissue ingrowth, and strength that reduces shearing forces. By using Dacron aortic graft, authors have reported a decrease in symptomatic instability with no increase in infection or reoperation rates[34]. Improvement of post-operative shoulder function was demonstrated and thought to be related to reattachment of the rotator cuff to Trevira tubes around the prosthesis[36]. Histopathological examination of the soft tissue surrounding Trevira tubes revealed ingrowth of fibrous tissues and no foreign body granuloma or inflammatory process[36]. LARS® was used to reconstruct soft tissue around four knees and three proximal femurs after tumor resection, and was found to be effective in improving stability and providing muscle attachment[22].

Being a retrospective study and having a heterogenic small sample size of patients are among the few study weaknesses followed by the fact that there was not a control group of patients without LARS to compare with. We identified two cases with dislocation (10.4%), although only one was symptomatically unstable. Follow up period was relatively short and it is possible that further proximal migration of the implant may be noted after a longer follow up period. However, migration tended to occur early on and then stabilized. Moreover, our classification proposal may have been thought to be among our study's weaknesses as it has never been described before. There was no other complication of significance including deep infection. Our works is among the few studies reporting about LARS for stabilization of proximal humeral prostheses. Some studies reported instability ranging between 0% and 11% using other types of fabric or techniques[16,34,36]. A recent series of interscapulothoracic resection for shoulder tumors found no difference in stability whether LARS was used or not[37]. Our study differs from others as we recorded progressive migration of the implant over time[38]. We found that most implants migrated superiorly and anteriorly. Implants stable in their end position were found to be without measurable clinical effect. Our only symptomatic patient had gross instability on every attempt at active shoulder motion.

Our study, as others, supports the reconstruction of the shoulder capsule as an effective way of minimizing symptomatic instability. It is unclear which, if any material would be superior to another. It remains unclear in other studies if there was a progressive superior and anterior migration of the implant over time, but it certainly could not be prevented with the LARS® and the suturing technique utilized here. Nevertheless, it resulted in a stable construct in 18 of the 19 cases and provided adequate function of the elbow and hand. Even in cases when there may be some migration, the consequences for stability and overall function would be of minor clinical relevance.

COMMENTS

Background

Malignant tumors or metastasis of proximal humerus may cause significant loss of function. Endoprosthetic replacement is the most common way to reconstruct the resected bony part following limb salvage procedure, provide normal use of the hand and elbow and optimize the shoulder's postoperative functional outcome.

Research frontiers

Shoulder implant instability leads to pain, discomfort, and inability to benefit of the functional outcomes of the procedure. Maintaining joint stability is challenging.

Innovations and breakthroughs

Use of the LARS® tube in the stabilization of proximal humeral endoprosthetic replacement for tumors and identification of any potential risk associated with its use.

Applications

Literature has advocated the use of various types of tissue, including synthetic or xenograft, to help reconstruct a new capsule over the proximal humeral endoprostheses and maintain the proper positioning and stability. This retrospective analysis revealed that facilitation of LARS tubes in the endoprosthetic replacement of the proximal humerus was not associated with specific complications and proved to provide good, although not perfect, shoulder stability. Longer length of follow up would be needed to confirm that proximal and anterior migration does not progress.

Terminology

LARS in an abbreviation for Ligament Advanced Reinforcement System. TESS is an abbreviation for toronto extremity salvage score. MSTS is an abbreviation for musculoskeletal tumor society score.

Peer-review

This article is very good.

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