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Universität Rostock
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Neue Aspekte zur komplexen kniegelenknahen Korrekturosteotomie

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Ausgewählte Publikationen

A Originalarbeiten (der kumulativen Habilitationsschrift zugrunde liegend)

1. Hinge screw or no hinge stabilization provides decreased stability compared to hinge plate in a biomechanical evaluation of distal femoral derotational osteotomies. **Ferner F**, Hammersdorfer N, Hembus J, Saß JO, Bader R, Klinder A, Hiepe L, Holl N, Lutter C. *Knee Surg Sports Traumatol Arthrosc.* 2024 Aug;32(8):2120-2128.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**, Osteotomiekomitee Deutsche Kniegesellschaft)
2. Intraoperative control by Schanz-screws is inaccurate to achieve the exact amount of correction in de-rotational osteotomies. **Ferner F**, Klinder A, Woerner M, Morris P, Harrer J, Dickschas J, Lutter C. *Knee Surg Sports Traumatol Arthrosc.* 2023 Oct;31(10):4319-4326.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**, Osteotomiekomitee Deutsche Kniegesellschaft)
3. Correction of tibial tubercle trochlea groove distance is related to torsional correction in high tibial derotational osteotomy. **Ferner F**, Dickschas J, Jasinski M, Huettner F, Harrer J, Lutter C. *Knee Surg Sports Traumatol Arthrosc.* 2023 Mar;31(3):1176-1182.
4. Perioperative complications in osteotomies around the knee: a study in 858 cases. **Ferner F**, Lutter C, Schubert I, Schenke M, Strecker W, Dickschas J. *Arch Orthop Trauma Surg.* 2022 May;142(5):769-775.
5. Medial open wedge vs. lateral closed wedge high tibial osteotomy - Indications based on the findings of patellar height, leg length, torsional correction and clinical outcome in one hundred cases. **Ferner F**, Lutter C, Dickschas J, Strecker W. *Int Orthop.* 2019 Jun;43(6):1379-1386.
6. Is a synthetic augmentation in medial open wedge high tibial osteotomies superior to no augmentation in terms of bone-healing? **Ferner F**, Dickschas J, Ostertag H, Poske U, Schwitulla J, Harrer J, Strecker W. *Knee.* 2016 Jan;23(1):2-7.

B Weitere Originalarbeiten zu kniegelenknahen Osteotomien

1. Significant slope reduction in ACL deficiency can be achieved both by anterior closing-wedge and medial open-wedge high tibial osteotomies: early experiences in 76 cases. Weiler A, Gwinner C, Wagner M, **Ferner F**, Strobel MJ, Dickschas J. *Knee Surg Sports Traumatol Arthrosc.* 2022 Jun;30(6):1967-1975.
2. The effect of open-wedge and closed-wedge high tibial osteotomies on the tibial posterior slope-a study of two hundred seventy-nine cases. Schubert I, **Ferner F**, Dickschas J. *Int Orthop.* 2020 Jun;44(6):1077-1082.

3. Patellofemoral dysbalance and genua valga: outcome after femoral varisation osteotomies. Dickschas J, **Ferner F**, Lutter C, Gelse K, Harrer J, Strecker W. Arch Orthop Trauma Surg. 2018 Jan;138(1):19-25.

C Übersichtsarbeiten zu kniegelenknahen Osteotomien

1. Korrektur komplexer Beindeformitäten mit Platten. Harrer J, Schröter S, Strecker W, **Ferner F**. Knie J. 2022. 4:27–34.
2. Handlungsalgorithmus: Vorgehen bei Hinge-Fraktur bei Tibiakopfoosteotomie. **Ferner F**, Lutter C, Harrer J. Knie J. 2024. 6:240–242.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**)
3. Patientenspezifische Schnittblöcke bei kniegelenknahen Korrekturosteotomien [Patient-specific cutting guides in corrective osteotomy near to the knee joint]. Harrer J, Lutter C, Hüttner F, Petersen W, Fürmetz J, **Ferner F**. Oper Orthop Traumatol. 2024 Apr;36(2):105-116. German.
4. Die Double-Level-Derotationsosteotomie am Kniegelenk [Double-Level De-Rotational Osteotomy of the Knee]. **Ferner F**, Lutter C, Perl M, Harrer J. Z Orthop Unfall. 2024 Jan 19. German.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**)
5. Anterior schließende subtuberositäre Osteotomie. Petersen W, **Ferner F**, Al Mustafa H, Häner M, Harrer J. Knie J. 2024. 6:98–102.
6. Transtuberositäre, ventral öffnende hohe Tibiaosteotomie zur Korrektur eines negativen Slope [Transtuberositary, Anterior Open Wedge High Tibial Osteotomy (TT-AOW-HTO) to Correct a Negative Slope]. Harrer J, **Ferner F**, Lutter C, Petersen W, Perl M, Simon M. Z Orthop Unfall. 2024 Oct 22. German.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**)

D Case-Reports zu kniegelenknahen Osteotomien

1. Retrograder Femursegmenttransportnagel – eine Anwendung bei posttraumatischem Knochendefekt mit Komplexdeformität [Retrograde bone transport nail in a posttraumatic femoral bone defect]. **Ferner F**, Lutter C, Dickschas J. Unfallchirurg. 2021 May;124(5):412-418. German.
2. Re-Correction Osteotomy for Overcorrection after Medial Opening Wedge High Tibial Osteotomy: A Case Report. Yoshida K, Ishijima M, **Ferner F**, Harrer J. Clin Surg. 2024;9(1):3714.

E Buchbeitrag zu kniegelenknahen Osteotomien

Kapitel: Knie nahe Osteotomien: Torsionskorrekturen. M. Engelhardt, M. J. Raschke (Hrsg.), Orthopädie und Unfallchirurgie, Springer Reference Medizin, **Ferner F**, Harrer J, Lutter C, published 10/24.
(Affiliationen Ferner, F.: Klinikum Lichtenfels, **Universitätsmedizin Rostock**)

Zusammenfassung der Habilitationsschrift

1 Zielstellung

Umstellungs-Osteotomien am Kniegelenk werden bereits seit vielen Jahrzehnten angewandt, seitdem Coventry die Technik wissenschaftlich aufgearbeitet hat. [1,2] Durch die Einführung winkelstabiler Implantate erfuhren Tibiakopf-Osteotomien nach der Jahrtausendwende bei Patienten mit unilateraler Gonarthrose eine gewisse Renaissance. [3,4] In den folgenden Jahren erhielten Umstellungsosteotomien daher regelmäßig Einzug auch im Bereich des distalen Femurs und das Indikationsspektrum wurde erheblich erweitert. [5-7] Zu erwähnen sind hier insbesondere axiale Korrekturen bei patellofemorale Pathologien sowie sagittale Korrekturen bei Rezidiv-Instabilitäten des vorderen und hinteren Kreuzbandes. [8-14] Gerade bei unilateraler Gonarthrose konkurrieren Umstellungsosteotomien in der Indikationsstellung mit der Knie-Endoprothetik, deren wissenschaftliche Evidenz aufgrund großer Fallzahlen vergleichsweise hoch ist. Außerdem erhöhte sich in unserer Gesellschaft innerhalb der letzten Jahrzehnte nicht nur die durchschnittliche Lebenserwartung, sondern vor allem auch der Aktivitätsanspruch bis ins hohe Alter. [15-17] Diese demographischen und gesellschaftlichen Veränderungen und die Medizin beeinflussten sich dabei stets gegenseitig. Um möglichst lange mit dem eigenen Gelenk diesem hohen Anspruch gerecht zu werden, wird womöglich auch der Anteil an gelenkerhaltenden operativen Alternativen zum Gelenkersatz in Zukunft zunehmen. Das Ziel dieser Arbeit ist die wissenschaftliche Darstellung von neuen Aspekten im Bereich der komplexen kniegelenknahen Korrekturosteotomie, hier insbesondere die Aufarbeitung von einzelnen Indikationen, speziell ausgewählten operativen Techniken und Komplikationen.

2 Methoden

Im Rahmen dieser Arbeit konnten wissenschaftliche Publikationen zu drei Themengebieten im Bereich „Kniegelenknahe Korrekturosteotomie“ zusammengefasst werden:

1. Techniken
2. Indikationen
3. Komplikationen

Hierbei werden im Wesentlichen erstmalig klinische Forschungsergebnisse in diesen Bereichen präsentiert und in den wissenschaftlichen Kontext bereits bestehender Literatur eingeordnet. Neben diesen klinischen Forschungsergebnissen wird in einer biomechanischen Analyse eine bestimmte komplexe Korrekturosteotomie-Technik und deren spezielle Osteosynthesetverfahren unter biomechanischen Aspekten labortechnisch untersucht.

3 Ergebnisse

Die Ergebnisse, die dieser kumulativen Habilitationsschrift zugrunde liegen, werden nun im Einzelnen präsentiert und unter den Themengebieten Techniken, Indikationen und Komplikationen zusammengefasst. Die Originalartikel sind dieser Arbeit unter Anlagen angefügt.

3.1 Techniken von kniegelenknahen Korrekturosteotomien

3.1.1. Augmentation des Osteotomiespalts

Is a synthetic augmentation in medial open wedge high tibial osteotomies superior to no augmentation in terms of bone-healing?

Ferner F, Dickschas J, Ostertag H, Poske U, Schwitulla J, Harrer J, Strecker W. Knee. 2016 Jan;23(1): 2-7.

Das Ziel dieser Publikation war die Beantwortung der Frage, ob die Verwendung von synthetischem Knochenersatzmaterial als Füllmaterial in den Osteotomiespalt die Knochenheilung bei der medial öffnenden (= MOW) Tibiakopf-Valgisations-Osteotomie positiv beeinflusst. Untersucht wurden hierzu 49 Patienten mit einer MOW-Tibiakopf-Osteotomie, wobei eine Unterteilung in zwei Gruppen stattfand: 19 Patienten, bei denen mit Tricalciumphosphat ein synthetisches Knochenersatzmaterial in den Osteotomiespalt eingefügt wurde und 30 Patienten ohne Auffüllung des Osteotomiespalts bei ansonsten gleicher Operationstechnik (Abbildung 1). Endpunkt war die knöcherne Heilung nach 6 und 12 Monaten, wobei die Osteotomie nach klinischen und radiologischen Kriterien entweder als „knöchern geheilt“ oder „Pseudarthrose“ klassifiziert wurde. Hierbei kam es in der Gruppe mit synthetischem Knochenersatzmaterial zu 5 revisionspflichtigen Pseudarthrosen (= 26 %), in der Gruppe ohne Knochenersatzmaterial nur zu einer Pseudarthrose (= 3 %). Dieser Unterschied

zwischen den beiden Gruppen war statistisch signifikant (p-Wert 0,027), wohingegen der Unterschied zwischen den Gruppen bezüglich demographischer Daten, Nikotinkonsum und Korrekturwinkel nicht statistisch signifikant unterschiedlich war. Somit konnte geschlussfolgert werden, dass die Verwendung eines Tricalciumphosphats als Füllmaterial für den Osteotomiespalt das Risiko für eine Pseudarthrose bei MOW-Tibiakopf-Valgisationsosteotomien erhöht.

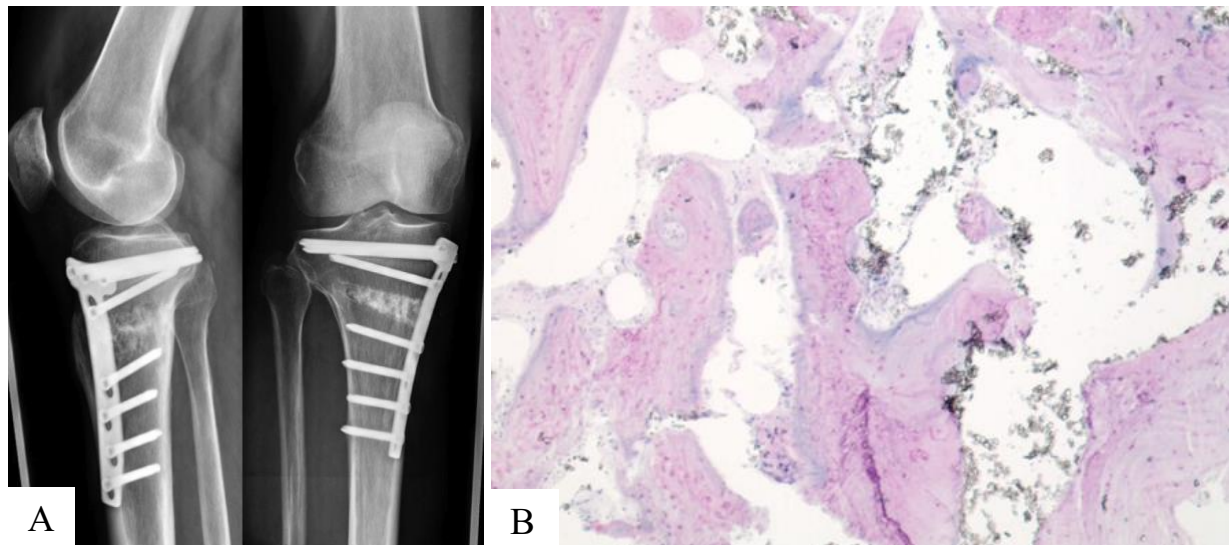


Abbildung 1

A. Seitliches und anterior-posterior Röntgenbild eines Patienten 9 Monate nach MOW-Tibiakopf-Valgisationsosteotomie. Wie im gesamten Kollektiv wurde die Osteotomie mittels winkelstabiler Platte von medial stabilisiert. In diesem Fall wurde der Spalt mit synthetischem Knochenersatzmaterial aufgefüllt und die Osteotomie als Pseudarthrose klassifiziert.

B. Histologischer Schnitt (Giemsa-Färbung) aus Material nach Auffüllung des Osteotomiespalts mit synthetischem Knochenersatzmaterial. Es zeigen sich bei diesem Patienten mit Pseudarthrose 24 Monate postoperativ noch residuelle Partikel des Tricalciumphosphats (grau) eingebettet in sich neuformierenden Knochen. (Modifiziert nach Ferner F et al., Is a synthetic augmentation in medial open wedge high tibial osteotomies superior to no augmentation in terms of bone-healing? Knee. 2016 Jan;23(1):2-7.)

3.1.2 Korrektur des TTTG-Abstands im Rahmen von tibialen Torsions-Osteotomien

Correction of tibial tubercle trochlea groove distance is related to torsional correction in high tibial derotational osteotomy.

Ferner F, Dickschas J, Jasinski M, Huettner F, Harrer J, Lutter C. Knee Surg Sports Traumatol Arthrosc. 2023 Mar;31(3):1176-1182.

Bisher gab es keine klinischen Erkenntnisse über die Veränderungen des TTTG (= tibial tubercle trochlea groove) Abstands im Rahmen einer Torsions-HTO (= Hoher Tibiakopf Osteotomie). Ziel dieser klinischen Studie war es daher, den Zusammenhang zwischen der Veränderung des TTTG-Abstands in Abhängigkeit vom Ausmaß der tibialen Torsionskorrektur herzustellen. Untersucht wurden 21 Fälle mit Torsions-HTO mittels prä- und postoperativem Torsionswinkel-CT (Computer-Tomographie): Es wurde dabei jeweils der tibiale Torsionswert und der TTTG-Abstand bestimmt und miteinander verglichen.

Es ergab sich eine starke Korrelation ($r= 0,90$) zwischen diesen beiden Werten sowie die Berechnung, dass sich der TTTG-Abstand bei dieser Technik der Torsions-HTO pro 1° Korrektur im Durchschnitt um 0,45 mm verringert ohne eine Veränderung der Patellahöhe (Tabelle 1, Abbildung 2). Dies ist für die Therapieplanung bei Patienten mit pathologisch erhöhter tibialer Torsion von entscheidender Bedeutung und höchster klinischer Relevanz.

	preoperative MV (SD; range)	postoperative MV (SD; range)
Tibial torsion in degree	46.21 (4.25; 35.5 – 55.9)	32.28 (5.54; 21.1 – 42.9)
TTTG distance in mm	15.69 (3.71;10.32 - 23.30)	9.38 (3.49; 5.32 – 16.8)
Caton-Deschamps Index (CDI)	1.03 * (0.18; 0.79 -1.45)	1.06 * (0.16; 0.79 - 1.43)

* Indicates no statistically significant difference using paired T-Test

Tabelle 1

Die Werte der tibialen Torsion und des TTTG-Abstands zeigen eine deutliche Veränderung zwischen prä- und postoperativ, während sich der CDI als Messwert für die Patellahöhe nicht verändert. (Modifiziert nach Ferner et al., Correction of tibial tubercle trochlea groove distance is related to torsional correction in high tibial derotational osteotomy, Knee Surg Sports Traumatol Arthrosc. 2023 Mar;31(3):1176-1182.)

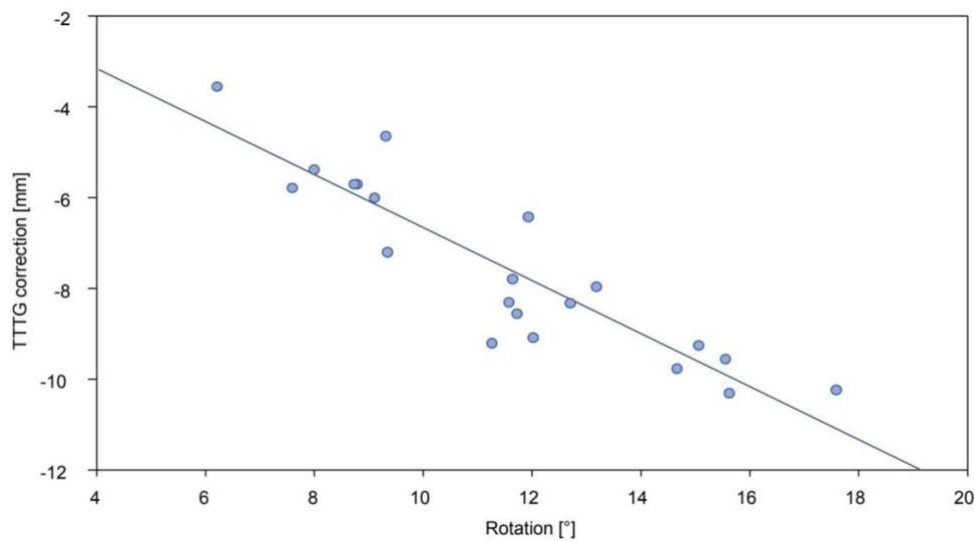


Abbildung 2

Hier ist die starke Korrelation ($r=0,902$) zwischen dem Ausmaß der Korrektur in $^{\circ}$ und dem TTTG-Abstand gezeigt. (Modifiziert nach Ferner et al., *Correction of tibial tubercle trochlea groove distance is related to torsional correction in high tibial derotational osteotomy*, *Knee Surg Sports Traumatol Arthrosc.* 2023 Mar;31(3):1176-1182.)

3.1.3 Intraoperative Messung des Korrekturausmaßes bei Torsions-Osteotomien

Intraoperative control by Schanz-screws is inaccurate to achieve the exact amount of correction in de-rotational osteotomies.

Ferner F, Klinder A, Woerner M, Morris P, Harrer J, Dickschas J, Lutter C. *Knee Surg Sports Traumatol Arthrosc.* 2023 Oct;31(10):4319-4326.

Das Ziel dieser klinischen Studie war es, die Genauigkeit der intraoperativen Messung des Korrekturausmaßes bei kniegelenknahen Torsionskorrekturen zu untersuchen. Hierfür wurden 28 femorale und 27 tibiale Torsionskorrekturen prä- und postoperativ mittels Torsionswinkel-CT untersucht und die im CT ausgemessenen Werte mit den intraoperativ gemessenen Werten verglichen. Wird eine Abweichung von $\pm 3^{\circ}$ als akzeptabel angenommen, so lagen nur 53,6% der femoralen und 51,9% der tibialen Korrekturen innerhalb dieser Grenze (Abbildung 3). Dabei zeigte sich eine Tendenz zur Überkorrektur bei femoralen und eine Tendenz zur Unterkorrektur bei tibialen Osteotomien ohne statistische Signifikanz. Außerdem konnte keine Korrelation zwischen dem Ausmaß der Korrektur und der Abweichung von der geplanten Korrektur festgestellt werden. Operateure müssen sich dieser intraoperativen Messungenauigkeit bei kniegelenknahen Torsions-Osteotomien bewusst sein und deshalb

postoperativ ggf. das erreichte Korrekturausmaß bildgebend mittels Torsionswinkel-Messung darstellen. Dies wurde bisher nicht als Standard bei Torsions-Osteotomien angesehen.

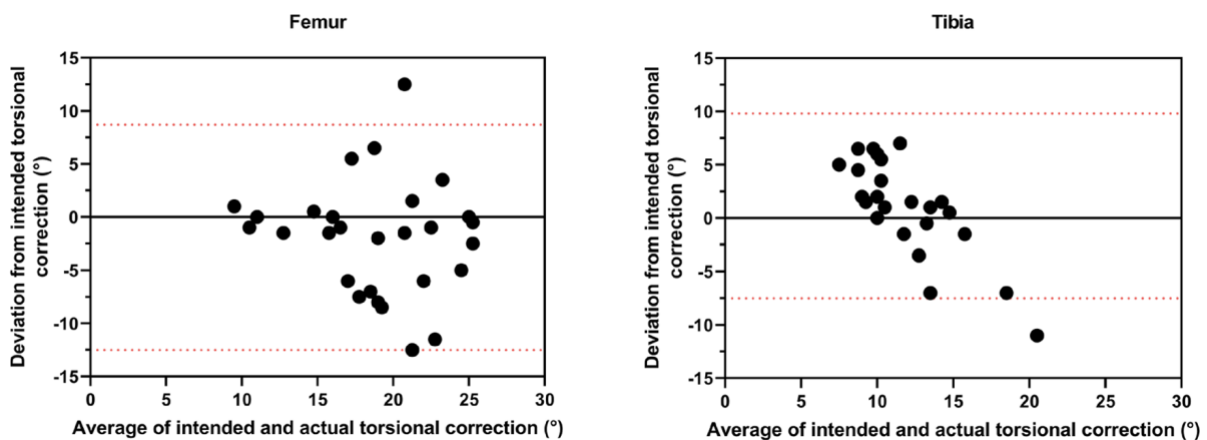


Abbildung 3

Graphische Darstellung der Werteabweichung der tatsächlichen Torsionskorrektur von der intraoperativ gemessenen Korrektur, unterteilt in femorale und tibiale Korrekturen. (Modifiziert nach Ferner et al., Intraoperative control by Schanz-screws is inaccurate to achieve the exact amount of correction in de-rotational osteotomies. Knee Surg Sports Traumatol Arthrosc. 2023 Oct;31(10):4319-4326.)

3.1.4 Biomechanischer Vergleich verschiedener Osteosynthese-Techniken bei femoraler Torsionsosteotomie

Hinge screw or no hinge stabilization provides decreased stability compared to hinge plate in a biomechanical evaluation of distal femoral derotational osteotomies.

Ferner F, Hammersdorfer N, Hembus J, Saß JO, Bader R, Klinder A, Hiepe L, Holl N, Lutter C. Knee Surg Sports Traumatol Arthrosc. 2024 Aug;32(8):2120-2128.

Das Ziel dieser Studie war es, die Stabilität der gängigen Osteosynthese-Techniken bei femoralen Torsions-Osteotomien biomechanisch zu testen. Hierzu wurden 15 Femur-Leichen-Präparate mit einer suprakondylären Torsionskorrektur in 3 Gruppen unterteilt:

1. Versorgung mittels medialer winkelstabiler Platte
2. Zusätzliche laterale Schraube (sog. Hinge-Schraube)
3. Zusätzliche laterale Platte.

Es folgte unter biomechanischen Bedingungen eine Testung unter axialer Last und Rotationsbewegung und Messung der Bewegungen im Osteotomiespalt, was als Stabilitätskriterium gewertet wurde (Abbildung 4). Bei axialer Last fanden sich die meisten

Mikro-Bewegungen in der Gruppe mit der unilateralen Platte, verglichen mit den beiden anderen Gruppen jedoch ohne statistisch signifikanten Unterschied. Bei zusätzlich rotatorischer Last zeigte sich verglichen mit den beiden anderen Gruppen statistisch signifikant weniger Bewegung im Osteotomiespalt in der Gruppe mit zusätzlich lateraler Platte. Es konnte demnach biomechanisch nachgewiesen werden, dass eine zusätzliche Hinge-Schraube gegenüber einer unilateralen medialen Platte keine zusätzliche Stabilität bringt, insbesondere nicht bei Rotationsbewegungen. Die Stabilität kann bei dieser speziellen Osteotomie nur durch eine zusätzliche laterale Platte erhöht werden.

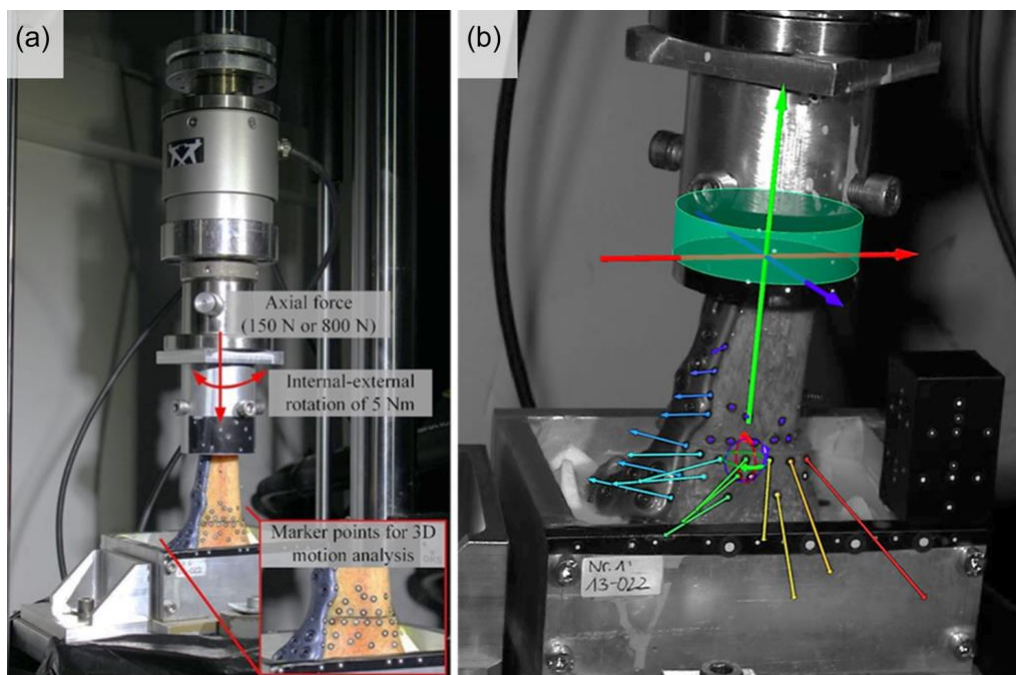


Abbildung 4

Dargestellt ist das experimentelle Setup mit dem in die Testmaschine eingebetteten Femur, das mit optischen Marker Punkten um den Osteotomiespalt herum versehen ist (a). Das Femur in der hydraulischen Testmaschine wird dann gezielten Kräften (axial / Rotation) ausgesetzt und die Bewegung im Osteotomiespalt gemessen (b). (Modifiziert nach Ferner et al., Hinge screw or no hinge stabilization provides decreased stability compared to hinge plate in a biomechanical evaluation of distal femoral derotational osteotomies. Knee Surg Sports Traumatol Arthrosc. 2024 Aug;32(8):2120-2128.)

3. 2 Indikationen zu kniegelenknahen Korrekturosteotomien

Indikationsstellung zur medial öffnenden vs. lateral schließende Tibiakopfosteotomie

Medial open wedge vs. lateral closed wedge high tibial osteotomy - Indications based on the findings of patellar height, leg length, torsional correction and clinical outcome in one hundred cases.

Ferner F, Lutter C, Dickschas J, Strecker W. Int Orthop. 2019 Jun;43(6):1379-1386.

Mit dieser Studie sollten die Unterschiede bezüglich Patellahöhe, Beinlänge, Torsionskorrektur und klinischem Outcome zwischen medial öffnender und lateral schließender Valgisations-HTO herausgearbeitet werden. Hierzu erfolgte die Auswertung von jeweils 50 konsekutiven Patienten, die mit der jeweiligen Technik operiert wurden. Im Ergebnis konnten keine Unterschiede zwischen beiden Gruppen bezüglich Wundheilungsstörung, knöcherner Heilung der Osteotomie, Operationszeit und klinischem Outcome nach einem Jahr festgestellt werden. Während sich die Patellahöhe bei der lateral schließenden HTO nicht ändert, wurde durch die medial öffnende Technik eine statistisch signifikante Verringerung der Patellahöhe beobachtet. Es fand sich in beiden Gruppen eine Verringerung des Tibialen Slope, wobei dies nur bei der lateral schließenden HTO statistisch signifikant war. Mit der medial öffnenden Technik wurde eine signifikante Beinverlängerung, mit der lateral schließenden Technik eine signifikante Beinverkürzung erreicht. Diese Veränderungen sind bei der Indikationsstellung neben der Tatsache, dass Torsionskorrekturen simultan nur bei der lateral schließenden Technik möglich sind, unbedingt zu beachten. Zur Indikationsstellung wurde aus den Ergebnissen der Studie ein Algorithmus erarbeitet (Abbildung 5).

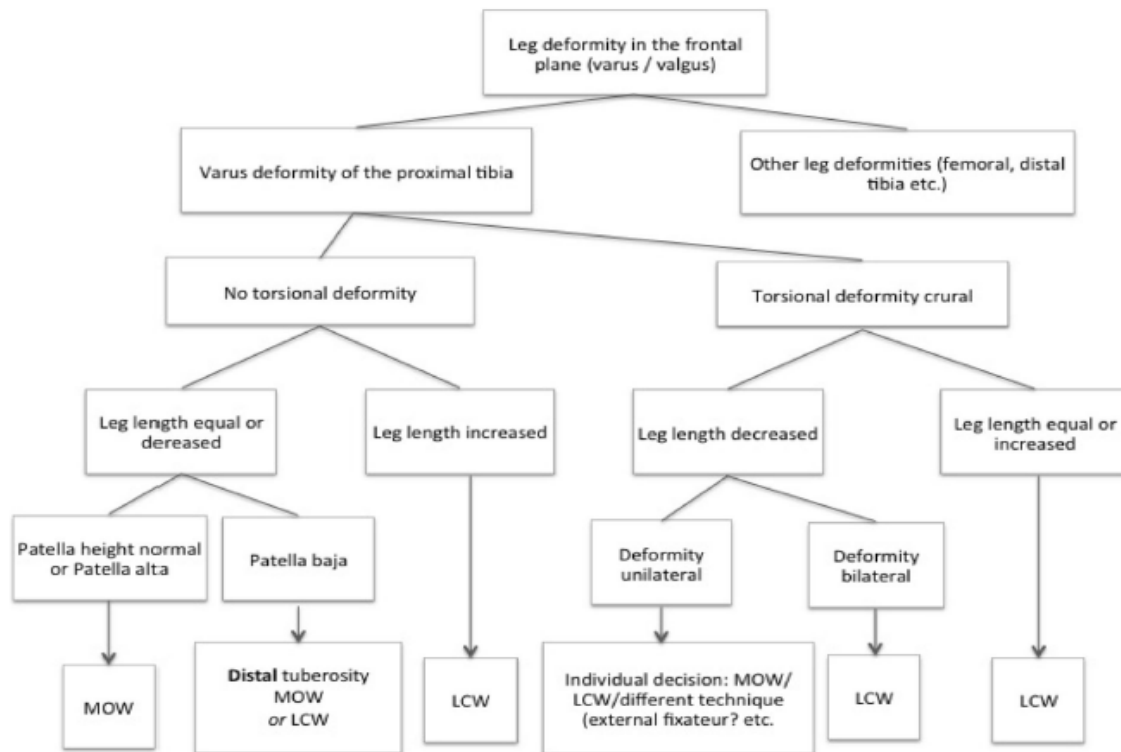


Abbildung 5

*Darstellung des Algorithmus, durch den aufgrund der Unterschiede bei Torsionsdeformitäten, Beinlängendifferenz und Patellahöhe die Indikation entweder zur lateral schließenden HTO (= LCW) oder zur medial öffnenden HTO (= MOW) gestellt werden kann. (Modifiziert nach Ferner et al., Medial open wedge vs. lateral closed wedge high tibial osteotomy - Indications based on the findings of patellar height, leg length, torsional correction and clinical outcome in one hundred cases. *Int Orthop.* 2019 Jun;43(6):1379-1386.)*

3.3 Komplikationen bei kniegelenknahen Korrekturosteotomien

Perioperative Komplikationen nach kniegelenknaher Umstellungsosteotomie

Perioperative complications in osteotomies around the knee: a study in 858 cases.

Ferner F, Lutter C, Schubert I, Schenke M, Strecker W, Dickschas J. *Arch Orthop Trauma Surg.* 2022 May;142(5):769-775.

Ziel dieser Studie war es, die perioperativen Komplikationen von kniegelenknahen Korrekturosteotomien zu erfassen. Hierzu wurden aus unserem Zentrum 858 Osteotomien im Hinblick auf intra- und früh-postoperative (vier Wochen postoperativ) Komplikationen analysiert und in Minor- und Major-Komplikationen unterteilt. Im erfassten Kollektiv kam es zu 15 Major- (1.7%) und 17 Minor-Komplikationen (2.0 %). Eine Auflistung der einzelnen

Komplikationen zeigt die Tabelle 2. Statistisch war das Risiko für eine Wundinfektion bei kontinuierlichen Korrekturen sowie bei posttraumatischen Deformitäten erhöht im Vergleich zu akuten Korrekturen und kongenitalen Fällen. Bei einer Bohrloch-Meißel-Osteotomie fand sich außerdem im Vergleich zu einer Säge-Osteotomie ein statistisch erhöhtes Risiko für eine Gefäßläsion. Es konnte kein statistisch signifikanter Zusammenhang zwischen der Osteotomie-Höhe (femoral versus tibial) und dem Auftreten von Komplikationen festgestellt werden. Insgesamt können kniegelenknahe Osteotomien daher mit einem Gesamtrisiko für eine perioperative Komplikation von 3,7 % als sichere Prozedur bewertet werden.

Complication	Number of cases
vascular lesion*	5
Compartment syndrome*	4
Deep infection*	6
Deep vein thrombosis**	3
Superficial wound infection/hematoma**	14

Tabelle 2

Die einzelnen Major- () und Minor- (**) Komplikationen sind aufgeführt. (Modifiziert nach Ferner et al., Perioperative complications in osteotomies around the knee: a study in 858 cases. Arch Orthop Trauma Surg. 2022 May;142(5):769-775.)*

4 Diskussion

Im Rahmen dieser Arbeit konnten die entscheidende Weiterentwicklung einzelner ausgewählter operativer Techniken komplexer kniegelenknaher Korrekturosteotomien dargestellt werden. So zeigte sich, dass bei der aktuell am häufigsten angewandten operativen Technik, der medial öffnenden Valgisations-HTO, die Verwendung eines synthetischen Knochenersatzmaterials keinen Vorteil bezüglich der Knochenheilung bringt, sondern das Risiko für eine revisionspflichtige Pseudarthrose sogar erhöht. Diese Erkenntnis wurde in der Folge im Rahmen von systematischen Reviews bestätigt, in denen verschiedene Materialien zum Auffüllen des Osteotomiespalts erfasst und miteinander verglichen wurden. Hierbei ergaben sich die besten Ergebnisse bezüglich der Knochenheilung bei der Verwendung von autologem

verglichen mit allogenen Knochen oder synthetischem Knochenersatzmaterial. [18] Eine weitere Arbeit konnte bestätigen, dass synthetisches Knochenersatzmaterial die knöcherne Heilung nicht positiv beeinflusst. [19] In dieser Arbeit verbesserten auch weder die Verwendung von autologem noch von allogenen Knochen die Knochenheilung. Aus diesem Grund sprechen die Autoren die Empfehlung aus, bei einem Korrekturwinkel von <10 mm bei gleichzeitiger Verwendung eines winkelstabilen Implantats den Osteotomiespalt nicht aufzufüllen.

Bei der Valgisations-HTO wurde die lateral schießende (LCW) Technik durch die medial öffnende Technik (MOW) mit der Verwendung winkelstabiler Implantate weitestgehend verdrängt. Dennoch behält die LCW bei bestimmten Indikationen noch immer ihren Stellenwert. Diese konnte durch den in dieser Arbeit dargestellten klinischen Vergleich der beiden Techniken klar gezeigt werden. Der aus den Ergebnissen abgeleitete Algorithmus zur Entscheidungsfindung über die zu verwendende Technik gibt eine entscheidende Hilfestellung bei kombinierten Torsionsdeformitäten und relevanter Beinlängendifferenz. Außerdem muss bei der MOW-Technik die Ausleitung der biplanaren Osteotomie von der Patellahöhe entweder nach proximal oder distal erfolgen. Diese Erkenntnis konnte in weiteren Arbeiten bestätigt werden. [20-23] Die Indikation zur jeweiligen Technik sollte daher differenziert in Abhängigkeit von der Beinlänge, einer Torsionsdeformität und der Patellahöhe gestellt werden.

Gerade bei der Indikationsstellung und Entscheidungsfindung bei unilateraler Gonarthrose und frontaler Deformität muss der Patient auch über Risiken und mögliche Komplikationen aufgeklärt werden. Während hier die Endoprothetik aufgrund großer Fallzahlen und Registerarbeiten eine verhältnismäßig gute Aufarbeitung aufweist [24-26], war die Evidenz im Bereich der kniegelenknahen Umstellungsosteotomien diesbezüglich bis zuletzt noch relativ gering. Umso wichtiger sind daher Arbeiten mit großen Fallzahlen. Mit der vorgestellten Studie ist mit 858 Osteotomien die größte Zahl aus einem Zentrum publiziert. Das Risiko für perioperative Komplikationen lag hier bei 1,7 % für Major- und bei 2,0 % für Minor-Komplikationen. Eine vergleichbare Studie berichtet bei insgesamt 243 Osteotomien aus einem operativen Zentrum über eine intraoperative Komplikationsrate von 1,2 %; dagegen lag die 90-Tage-Komplikationsrate mit 42 % deutlich höher, wobei hier im Einzelnen das Risiko für interventionsbedürftige postoperative Bewegungseinschränkung (17,7 %), Wundinfektion (13,2 %), Hämatome (6,6%) und tiefem Infekt (4,1%) deutlich höher lag bei einem jedoch verlängertem Beobachtungszeitraum von 90 Tagen. [27] In einem aktuellen systematischen Review [28] lag die Inzidenz für intraoperative Komplikationen mit 5,5 % höher als im eigenen

Kollektiv. Jedoch wurden in der eigenen Studie intraoperative Hinge-Frakturen nicht erfasst. Auch postoperativ lag die Komplikationsrate mit 6,5 % höher, da zum einen der Nachbeobachtungszeitraum länger war und zum anderen auch die knöchernen Heilung miteingefasst wurde. Die Infektionsrate lag im eigenen Kollektiv (0,7 %) mit 1,2 bis 1,9 % [29] etwas niedriger als in anderen Studien. Der große Unterschied zur Infektbehandlung im Rahmen von Osteotomien verglichen mit periprothetischen Infektionen liegt darin, dass der Infekt nach Osteotomien in der Regel spätestens durch Entfernung sämtlichen Fremdmaterials ausgehend werden kann und häufig kein Korrekturverlust zurückbleibt. [30,31]

Torsions-Osteotomien

Drei Studien dieser kumulativen Habilitationsarbeit beschäftigen sich mit kniegelenknahen Torsions-Osteotomien. Hierbei einige entscheidende neue Erkenntnisse gewonnen werden: Erstmals konnte die Veränderung des TTTG-Abstands im Rahmen einer tibialen Torsions-HTO klinisch nachgewiesen und die Veränderung gleichzeitig quantifiziert werden. Bisherige Erkenntnisse waren auf theoretische Überlegungen oder Simulationen begrenzt. [32] Die Komplexität patellofemoraler Pathologien ist allgemein bekannt und jede Pathologie muss separat untersucht und bei Bedarf individuell adaptiert operativ adressiert werden entsprechend einer „Chirurgie à la carte“. [33-36] Umso wichtiger ist die Erkenntnis, dass mit dieser Technik zwei Pathologien gleichzeitig behoben werden können, insbesondere da beide Pathologien unabhängig voneinander auftreten. [37]

Darüber hinaus konnte gezeigt werden, dass bei kniegelenknahen Torsions-Osteotomien die intraoperative Kontrolle mit 5-mm-Schanz-Schrauben relativ ungenau ist und etwa jede zweite Korrektur um >3 Grad von der intraoperativ gemessenen Korrektur abweicht. Dessen muss sich der Operateur bewusst sein, insbesondere bei sehr kleinen Korrekturwinkeln. Gegebenenfalls ist hier postoperativ zusätzlich zu den Standard-Röntgenbildern die Veranlassung einer Torsionswinkel-Messung nötig, um das tatsächlich erreichte Korrektur-Ausmaß zu kontrollieren und zu dokumentieren. Vergleichbar ist dies mit der Versorgung von Schaftfrakturen in der Traumatologie, wo mittlerweile im Zweifelsfall trotz vermeintlich korrekter Reposition auch eine Torsions-Messung empfohlen wird. [38] Alternativ sollte die bisher als Goldstandard verwendete Technik zur intraoperativen Messung überdacht und weiterentwickelt werden. Erste Ansätze unter der Verwendung digitaler Tools wurden bereits in der Traumatologie bzw. am Kadaver beschrieben. [39-43]

Während es zur distalen Femur-Osteotomie (= DFO) Literatur zur biomechanischen Stabilität gibt [44,45], existierte zur femoralen Torsions-Osteotomie bisher keine biomechanische

Testung. Es konnte erstmals gezeigt werden, dass die in letzter Zeit häufiger propagierte „Hinge-Schraube“ im Vergleich zu einer unilateralen Platte keine relevante Verbesserung der Stabilität bringt. Nur eine zusätzliche kontralaterale Platte kann die Stabilität insbesondere im Hinblick auf Rotationskräfte signifikant verbessern. Dies unterstützt die bisherigen Erkenntnisse über die Instabilität bei Hinge-Frakturen im Rahmen einer DFO. [46-49]

5 Schlussfolgerung

Im Rahmen einer Tibiakopf-HTO wird kein synthetisches Knochenersatzmaterial zum Auffüllen des Osteotomiespalts empfohlen. Während am Tibiakopf die MOW-Technik mittlerweile breite Anwendung findet, sollte die LCW-Technik weiterhin bei relevanter Beinlängendifferenz sowie simultaner Torsionskorrektur entsprechend einem Algorithmus erwogen werden. Bei der Torsions-HTO wird der TTTG-Abstand bei einer biplanar supratuberositär angewandten Technik pro Grad Korrektur um ca. 0,45 mm reduziert. Bei der femoralen Torsionskorrektur muss bei der Standard-Technik mittels einer winkelstabilen Platte auf eine biomechanisch instabile Situation hingewiesen werden, v.a. gegenüber Rotationskräften. Verbessert wird dies nur durch eine zusätzliche kontralaterale Platte. Dies ist im Vorfeld bei der Indikationsstellung hinsichtlich Risikofaktoren zu beachten. Generell ist bei Torsionskorrekturen die aktuell verwendete Technik mittels Goniometer und Schanz-Schrauben zur Ausmessung der intraoperativen Torsionskorrektur relativ ungenau. Insgesamt stellt die kniegelenknahe Korrekturosteotomie ein relativ sicheres Verfahren dar mit einem perioperativen Risiko von 1,7 % für Major- und 2,0 % für Minor-Komplikationen.

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Anlagen

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C *Abkürzungsverzeichnis (alphabetisch)*

CDI = Caton-Deschamps Index

CT = Computer Tomographie

DFO = Distale Femur-Osteotomie

HTO = Hohe Tibiakopf-Osteotomie

LCW = Lateral closed wedge

MOW = Medial open wedge

SD = Standard deviation

TTTG = Tibial tubercle trochlea groove

D Vollständige Publikationsliste inklusive Impact Faktor (IF)

Zusammenfassung:

Originalarbeiten – Erstautorenschaft	6
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- ESSKA Specialty Days, Warsaw, 25.11.23
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- 25. Kurs zur Analyse und Korrektur von Beindeformitäten, Schloss Reisenburg, 5.10.23
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- AE Kompaktkurs Spezial - München, 15.7.22
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- Osteotomie-Kurs Kloster Banz, 4.5.18
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6. Originalarbeiten der Habilitationsschrift

Hinge screw or no hinge stabilization provides decreased stability compared to hinge plate in a biomechanical evaluation of distal femoral derotational osteotomies

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Abstract

Purpose: Derotational distal femoral osteotomy (DFO) is the causal treatment for patients with femoral torsional deformity. The fixation is achieved by a unilateral angle-stable plate. Delayed- or non-unions are one of the main risks of the procedure. An additional contralateral fixation may benefit the outcome. Therefore, we hypothesize that primary stability in DFO can be improved by an additional fixation with a hinge screw or an internal plate.

Methods: Derotational DFO was performed in 15 knees and fixed either with an angle-stable plate only (group 'None'), with an additional lateral screw (group 'Screw') or with an additional lateral plate (group 'Plate'). Biomechanical evaluation was carried out under axial loading of 150 N (partial weight bearing) and 800 N (full weight bearing), followed by internal and external rotation. After linear axial loading in step 1, a cyclic torsional load of 5 Nm was applied under constant axial load in step 2. In step 3, the specimens were unloaded. Micromovements between the distal and proximal parts of the osteotomy were recorded at each step for all specimens.

Results: In step 1, the extent of micromovements was highest in group 'None' and lowest in group 'Plate' without being significantly different. In step 2, group 'Plate' showed significantly higher stability, reflected by less rotation and lower micromovements. Increasing the axial load from 150 to 800 N at step 2 resulted in increased stability in all groups but only reached significance in group 'None'.

Conclusion: An additional contralateral plate significantly increased stability in derotational DFO compared to the unilateral angle-stable plate only. Contrary, a contralateral hinge screw did not provide improved stability.

Study Design: Experimental study.

Abbreviations: DFO, distal femoral osteotomy; MPFL, medio-patellofemoral ligament; PFI, patellofemoral instability.

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Level of Evidence: IV.

KEYWORDS

biomechanical analysis, derotational femoral osteotomy, hinge-screw, knee osteotomy, plate stabilization

INTRODUCTION

Derotational distal femoral osteotomy (DFO) is the treatment of choice in patients with torsional femoral deformity. The condition is often associated with complex lower leg abnormalities [8, 14, 17, 26, 34]. Clinically, these patients present with patellofemoral instability (PFI) or anterior knee pain caused by patellofemoral maltracking [29]. After the failure of conservative treatment or single reconstruction of the medio-patellofemoral ligament (MPFL), the causal surgical therapy consists of derotational DFO [4, 8, 11, 13, 19, 37]. Different techniques for derotational DFO and stabilization of the femur via an internal plate fixator have been described and are well-established clinical practice [6, 10, 23, 24]. However, delayed- or non-unions are one of the most common complications with DFO. They are indeed specific for this osteotomy technique, where a complete cut of the bone is required, as compared to frontal plane osteotomies. Lately, some surgeons used a contralateral stabilization in high tibial osteotomies in order to stabilize the lateral hinge [5, 16, 36]. This approach was adapted in derotational DFO without evidence or clinical proof of its increased biomechanical stability. Recently, Peez et al. published a biomechanical study about the different stabilization techniques in hinge fractures in medial closed and lateral open wedge DFO [28]. They reported a decreased stability after hinge fractures compared to an intact contralateral hinge. Stability was partly restored when the hinge fracture was stabilized by a contralateral plate. However, the biomechanical conditions from their study cannot be transferred to derotational DFOs.

The aim of this study was to evaluate the biomechanical impact of different types of fixation techniques in derotational DFOs. It was hypothesized that an additional stabilization by contralateral hinge screw or plate fixation improves primary biomechanical stability compared to sole fixation with a unilateral internal plate in derotational DFOs that involve a straight diaphyseal osteotomy cut. To test this hypothesis, derotational osteotomies of human distal femurs with a correction angle of 20° external rotation of the distal fragment were stabilized with either a medial locking plate, a medial locking plate plus a lateral hinge-screw or a medial

locking plate plus a contralateral plate. The effectiveness of stabilization was biomechanically evaluated.

MATERIALS AND METHODS

Materials and preparation

A derotational osteotomy with a correction angle of 20° external rotation of the distal fragment was performed on 15 fresh-frozen left human femoral bones. The study was approved by the local ethics committee (approval number: A 2020-0098). The specimens were obtained from body donations from the local Institute of Anatomy. The amount of correction was controlled with Kirschner wires (K-wires) and a goniometer to achieve a 20° angle of correction. The K-wires were removed after fixation with the plate. The osteotomy height was defined according to the technique by Strecker [5, 16, 36] at the distal femoral diaphysis (Figure 1). The osteotomy was performed with an oscillating saw in a uniplanar manner from the medial aspect of the femur perpendicular to the (assumed) mechanical axis in the frontal and sagittal plane and fixed with an angle-stable locking plate (Activmotion, Distal Femoral Osteotomy Plate, Newclip Technics). The 15 specimens (59–91 years, 10 female, 5 male) were divided into three groups of five specimens, matched for sex and age: group 'None': no additional contralateral stabilization, group 'Screw': additional lateral hinge screw (Initial K Hinge Screw, Newclip Technics) and group 'Plate': additional lateral angle stable plate (Activmotion, Distal Fibular Osteotomy Plate, Newclip Technics). The different types of fixations are shown in Figure 2.

All 15 fresh-frozen human specimens were analysed by measuring bone mineral density before the osteotomy to avoid significant differences in bone density between the different groups. The bone density was measured by peripheral quantitative CT (XCT 3000 pQCT scanner, Stratec Medical) at three different levels to determine the density of the whole bone section as well as cortical and cancellous bone at the epiphysis, metaphysis, and diaphysis levels (Table 1). Moreover, radiographs in two planes were taken prior to the osteotomy and after completing fixation to detect bone fractures

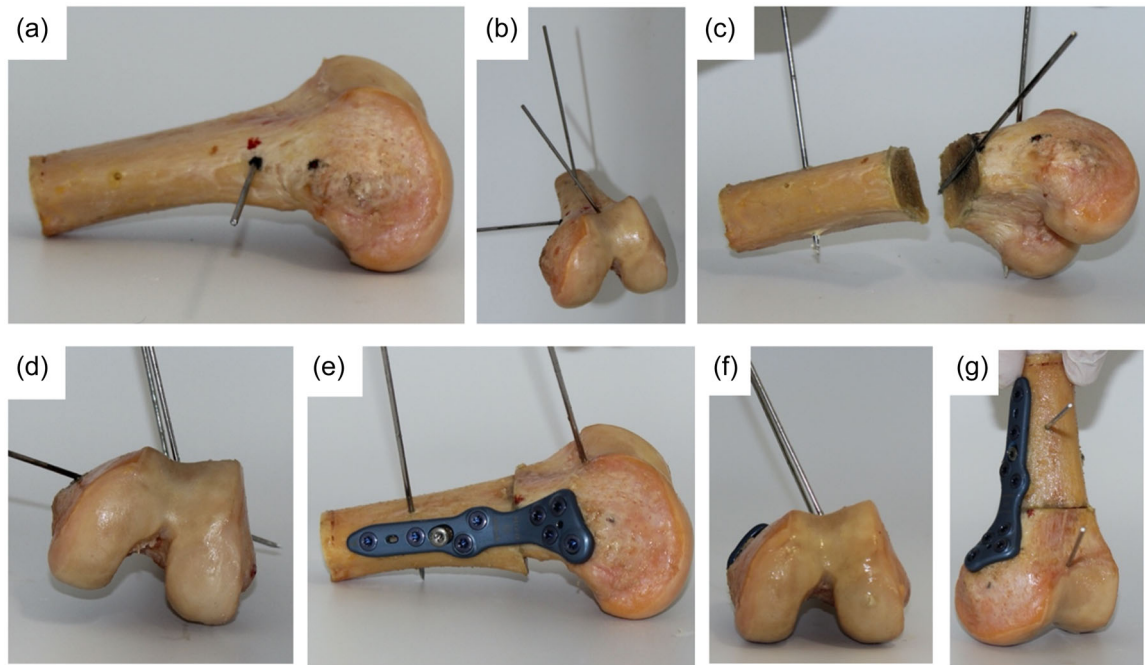


FIGURE 1 The first K-wire (a) indicated the plane of the osteotomy perpendicular to the mechanical axis of the femur at the distal diaphysis. One K-wire was inserted in each fragment (distal and proximal) at an angle of 20°, indicating the amount of correction (b). The osteotomy was performed proximal to the K-wire (c), and the K-wires were parallelized (d). In this position, the fragments were fixed with a medial angle stable plate (e). The parallel position of the K-wires was checked after completing the osteosynthesis (f, g).

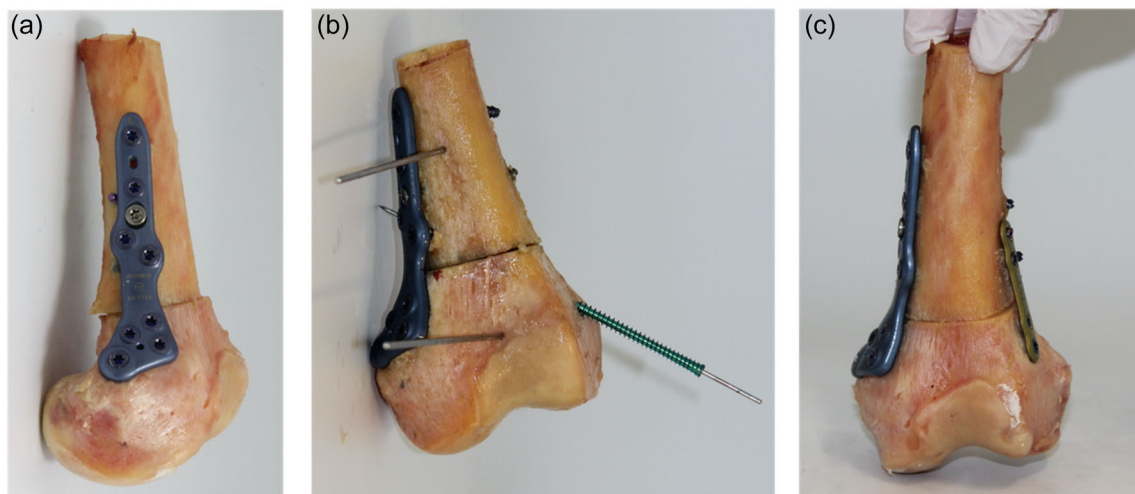


FIGURE 2 (a) Group 'None': fixation solely with medial locking plate. (b) Group 'Screw': fixation with medial locking plate and lateral hinge screw. (c) Group 'Plate': fixation with medial locking plate and lateral plate.

and to document the correct fixation and closing of the osteotomy gap (Figure 3).

The prepared femoral bones were then embedded into aluminium containers (proximally and distally) using resin and filler (resin and hardener: Rencast FC 52 polyol and isocyanate, Huntsman Advanced Materials; filler: DT 082-1 aluminium hydroxide, Goeßl & Pfaff) [2]. Finally, the specimens were marked with optical measuring points for 3D motion analysis [7, 31]. The whole process from

thawing the specimens to finalizing the biomechanical tests was standardized for all knees. The tests were started 12 h after all specimens were fully defrosted and finished another 12 h later.

Biomechanical evaluation

For biomechanical testing, a constant axial load as well as an internal and external rotation of 5 Nm with a

TABLE 1 The specimens were distributed to the three groups according to age and gender (as equal age distribution as possible, one specimen of a male cadaver per group, the other specimens were all females).

Group	Age in years (MV; range; SD)	Bone density in mg/ccm								
		Epiphysis (MV; range; SD)		Metaphysis (MV; range; SD)		Diaphysis (MV; range; SD)				
		Ent.	Canc.	Ent.	Canc.	Ent.	Canc.			
None	85.2;	202.46;	199.02;	233.56;	206.98;	179.44;	454.46;	589.7;	195.34;	912.08;
	80–91;	126–301.1;	126.8–297.8;	119.6–330.8;	101.5–284.1;	69.4–253.7;	361.3–556.6;	404.8–707.3;	62.2–294.8;	684.9–1057.8;
	4.15	63.76	62.54	78.07	68.43	69.53	80.36	125.03	94.88	150.21
Screw	78.0;	194.9;	191.33;	227.18;	217.76;	192.38;	445.92;	710.78;	274.98;	1067.18;
	59–86;	169.5–223.1;	165.8–216.6;	161.2–281.9;	195.1–266.1;	173.2–240.2;	228.2–615.4;	642.0–789.3;	191.3–356.9;	1010.7–1142.6;
	10.82	22.1	22.04	55.45	29.66	27.72	142.11	58.9	68.28	52.59
Plate	82.0;	204.33;	199.7;	245.93;	259.97;	230.43;	525.83;	671.5;	246.47;	1018.9;
	76–87;	198.4–213.5;	193.6–207.3;	226.9–269.3;	243.2–281.0;	220.1–245.9;	404.8–596.4;	616.5–754.0;	169.0–337.7;	930.3–1094.2;
	5.58	8.05	6.1	21.53	19.26	13.64	105.3	72.76	85.19	82.76

Note: The difference in bone density was not significant (n.s., $p > 0.05$) in any of the analysed bone densities (ent. = entire, canc. = cancellous, cort. = cortical, MV = mean value, SD = standard deviation, mg = milligram, ccm = cubic centimetre).

frequency of 0.25 Hz was applied using a servo-hydraulic test machine (Instron® 8874, Instron GmbH) following pretest loading with 50 N axial load. The experimental setup is shown in Figure 4. Thereby, the biomechanical test consisted of three consecutive steps. In step 1, all specimens were linearly loaded with an axial load of initially 150 N (partial weight bearing) and in a second setup with 800 N (full weight bearing). In step 2, a sinusoidal torsional load of 5 Nm was additionally applied over 10 cycles in both setups after the respective axial load was reached. In step 3, the specimens were unloaded [2].

The relative micromovements between the distal and proximal part of the femoral osteotomy, resulting from the axial and torsional loads, were recorded using an optical 3D measurement system (ARAMIS 5M, 23 mm lenses, Carl Zeiss GOM Metrology GmbH). The micromovements between the femoral fragments were analysed using GOM Suite 2021 (v3.1, Carl Zeiss GOM Metrology GmbH). This was achieved by detecting and recording the displacements of the optical markers in all three spatial directions (X-, Y- and Z-axes). The axes were defined as transversal axis (X), longitudinal axis (Y) and sagittal axis (Z) (Figure 4). This analysis was performed for the entire proximal and distal femoral fragment on the one hand but also for their respective parts medially, ventrally and laterally along the osteotomy plane [31, 32].

Statistical analysis

Microsoft Excel was used for data collection; statistical analyses were performed using GraphPad Prism 9.2 (GraphPad Software, Inc.). Values were checked for normal distribution with the Shapiro–Wilk test. To determine significant differences, two-way ANOVA and Bonferroni's multiple comparison tests were used. Unless stated otherwise, data are expressed as mean and standard deviation with range, as appropriate. Values of $p < 0.05$ were considered statistically significant.

RESULTS

Analysing step 1 (increasing axial load of 150 or 800 N along the Y-axis), the resulting mean values of the recorded micromovements at both 150 and 800 N were largest for Group 'None' ($m = -0.07 \pm 0.09$ mm at 150 N and -0.31 ± 0.44 mm at 800 N) and lowest for Group 'Plate' ($m = -0.02 \pm 0.01$ mm at 150 N and -0.10 ± 0.08 mm at 800 N). However, the observed differences in the relative micromovements along the axes are not statistically significant (n.s., $p > 0.05$). All groups showed a higher extent of micromovements under axial loading at 800 N (full weight bearing) compared to 150 N

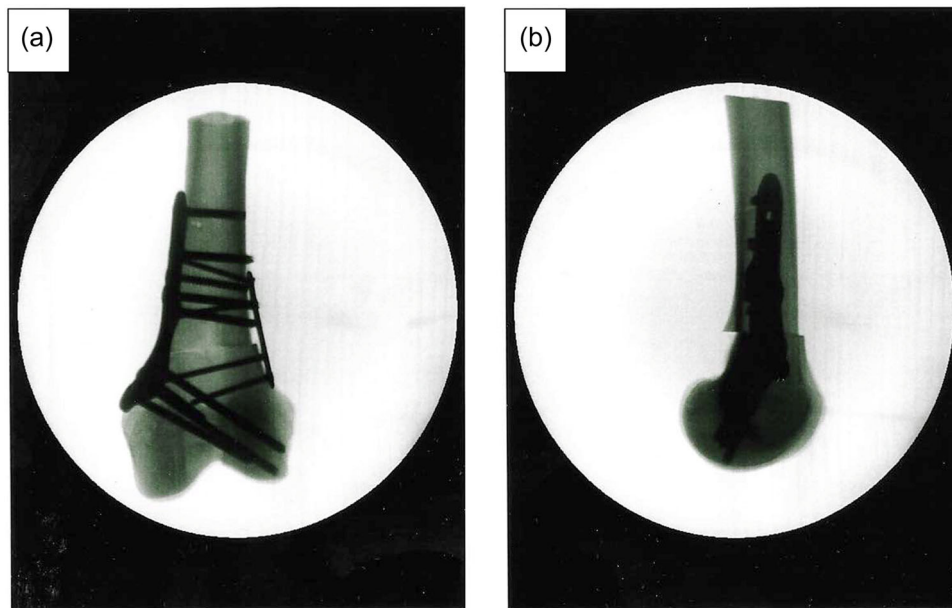


FIGURE 3 The anterior–posterior (a) and lateral (b) radiographs show a femur of group ‘Plate’ after osteotomy with a medial locking plate and an additional contralateral plate. The correct positioning of the implants and the closure of the osteotomy gap are documented in two planes.

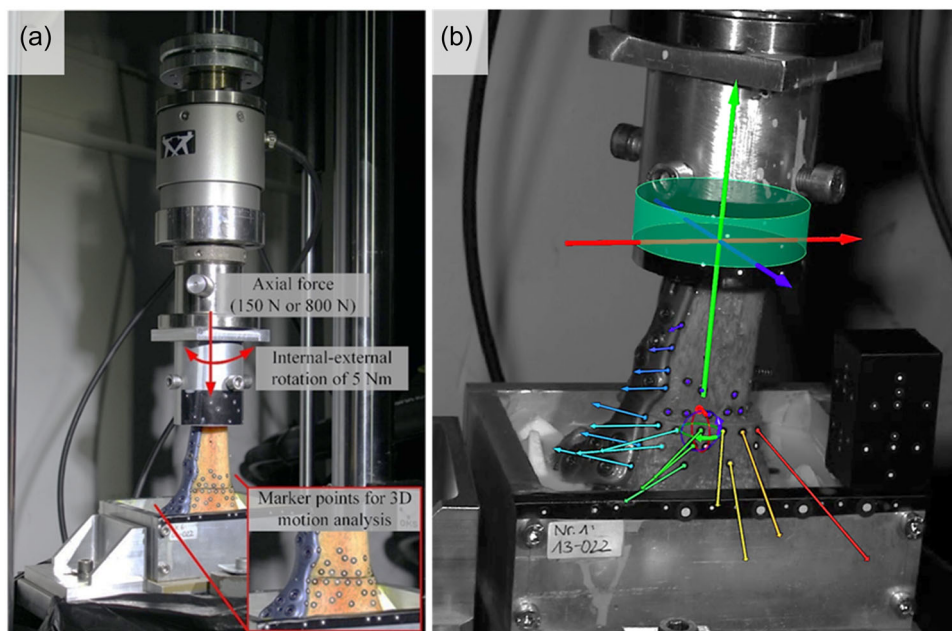


FIGURE 4 (a) The experimental setup shows the embedded femur in the testing device. Optical marker points are put on the femur. (b) Femur inserted in servo-hydraulic test machine during test (N = Newton, Nm = Newton-metre, 3D = three-dimensional).

(partial weight bearing), but again differences were n.s. ($p > 0.05$). The results are shown in Figure 5a.

During step 2 at partial weight bearing (150 N), specimens of group ‘None’ showed the largest micromovements ($m = -0.27 \pm 0.25$ mm) along all three axes. The smallest micromovements along the axes were observed in specimens of group ‘Plate’ ($m = -0.04 \pm 0.03$ mm). Only the differences in the micromovements of the femoral fragments between

group ‘None’ and ‘Plate’ were found to be statistically significant ($p < 0.05$). Thus, the femoral osteotomy with an additional angle-stable plate from the lateral side was more stable than the one with a unilateral medial plate at an axial and additional torsional load with partial weight bearing (Figure 5b).

When considering the rotation of the distal femoral fragment against the proximal around the Y-axis in step 2 at partial weight bearing, the resulting torsion angle of

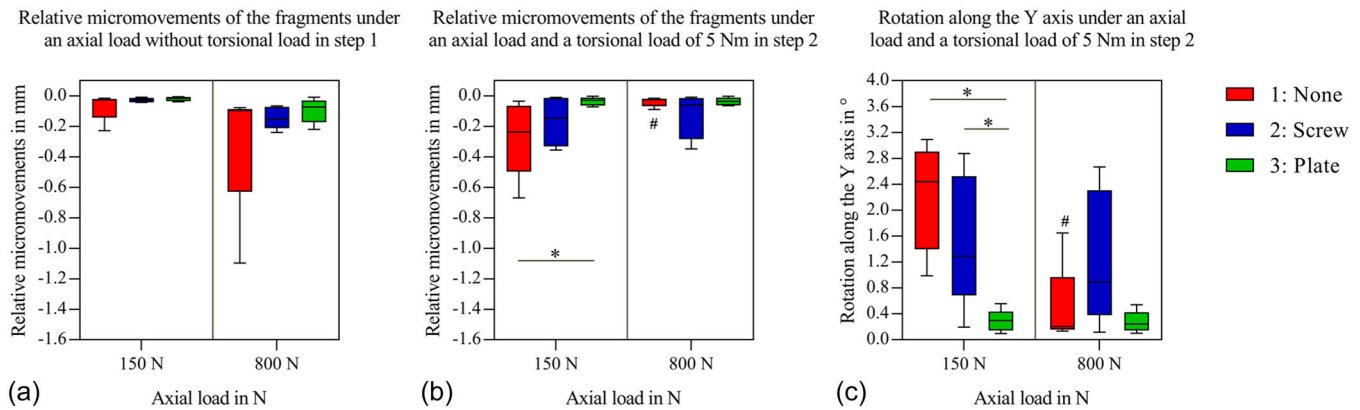


FIGURE 5 The boxplots show the results of: (a) Step 1: resulting relative micromovements at rising axial load along the Y-axis with 150 and 800 N. (b) Step 2: resulting relative micromovements at cyclic torsional load of 5 Nm under constant axial load of 150 and 800 N. (c) Step 2: resulting rotation of the distal against the proximal femoral fragment along the Y-axis at a cyclic torsional load of 5 Nm under a constant axial load of 150 and 800 N. Statistical analysis was performed with two-way ANOVA and Bonferroni post hoc test. All significant differences ($p < 0.05$) were depicted in the graphs: * significantly different between the different designs under the same loading; # significantly different between 150 and 800 N for the same design.

group 'Plate' ($0.29 \pm 0.17^\circ$) was significantly lower than the one of group 'None' ($2.21 \pm 0.83^\circ$, $p < 0.05$) and group 'Screw' ($1.54 \pm 1.02^\circ$, $p < 0.05$), while 'None' and 'Screw' did not differ significantly. Torsional osteotomy with an additional contralateral plate allowed significantly less rotation under torsional loading than a fixation with a lateral hinge screw or without further lateral fixation (Figure 5c).

At full weight bearing (800 N axial load), the different groups did not differ significantly in any of the micromovements or rotations around the Y-axis. Additional lateral stabilization with an angle-stable plate or Hinge-screw did not provide any advantages in terms of stability against torsional loads at full weight bearing (Figure 5b).

In the three groups, torsion and micromovements in the three groups were usually smaller at an axial load of 800 N than 150 N. However, this reduced mobility at full weight bearing was only found to be statistically significant in group 'None' ($p < 0.05$ for relative movements and $p < 0.0001$ for torsion) (Figure 5b,c).

DISCUSSION

The most important finding of the current study was that the stabilization with a unilateral angle stable plate in derotational DFOs was less stable compared to additional contralateral plate fixation under partial weight bearing (150 N). An additional contralateral hinge screw did not provide a significant improvement in stability compared to a unilateral angle stable plate.

There are no data in the literature on the non-union rate in derotational osteotomies, but bone healing and resulting non-union is one of the most challenging aspects following this procedure [33]. For medial

closing DFO, the radiographically diagnosed rate for non-unions is approximately 3.2% and 3.8% for delayed union, as reported by Wylie et al. [35]. Some authors observed higher rates for hinge fractures using CT scans. Nakayama et al. reported a risk of 30.6% in 36 knees after lateral closed wedge DFO. Similarly, Matsushita et al. found a risk of 32.0% [21, 22]. As hinge fractures of the DFO are associated with delayed bone healing and increased risk of non-union [9, 30], contralateral fixation has been discussed to improve the stability and decrease the risk of non-union in hinge fracture. This is supported by the biomechanical findings of Matsushita et al. [20]. The authors investigated the stability of hinge fractures in the medial closing DFO in a study of 10 specimens and found that a lateral hinge plate significantly reduced abnormal lateral movements in cases of a lateral hinge fracture. In their retrospective analysis of distal femoral fractures, Bologna et al. demonstrated a lower rate of non-union rate in cases with dual plate fixation compared to unilateral plate fixation [1]. Moreover, the application of a contralateral hinge screw decreased the translation and rotation of the fragments. However, the effect was not statistically significant, which is consistent with the results of the current study.

In derotational DFOs, the contralateral hinge must be cut to achieve the torsional correction. Thus, the situation may be comparable with an unintentional hinge fracture in frontal-plane corrections in terms of instability, despite the more distal location of the hinge fracture and the osteotomy when compared to the osteotomy cut in derotational DFOs. Several studies showed that bone healing and stability are better in the metaphyseal region. However, derotational DFOs cannot be performed further distally because of the shape of the distal femur and the resulting possibility of

compromising the patellofemoral joint at correction angles of at least 10° [18, 25, 27]. Moreover, the angulation of the osteotomy cut in DFO is important for bone healing. Brinkmann et al. found a significantly higher stability in DFOs with an oblique compared to a perpendicular cut [3]. In derotational DFO, the plane of the osteotomy cut must be planned preoperatively to achieve the proper correction in the frontal plane [12]. Three-dimensional calculations are necessary to avoid unintentional effects on the frontal plane. The plane of the osteotomy in derotational DFO should therefore be perpendicular to the virtual femoral shaft axis to avoid unintentional frontal plane changes [15]. This means that in derotational DFO the contact surface of the bone is decreased compared to oblique osteotomies in frontal plane corrections with a hinge fracture. For the latter, Peez et al. found in their biomechanical study that an additional contralateral plate significantly increased rotational stability compared to a unilateral plate or to a unilateral plate combined with a contralateral hinge-screw [28]. The results were obtained from a cadaver study of medial closed wedge and lateral open wedge DFO for a biplanar and uniplanar technique with two specimens apiece with an axial load of 400 N. Although their main results were confirmed by our study, the biomechanical and anatomical conditions differ between a frontal plane osteotomy with an oblique metaphyseal osteotomy and a straight diaphyseal osteotomy in derotational DFOs and the results cannot be transferred unconditionally from one study to the other.

A possible explanation for the increased stability under torsional load at 800 N in the presented study could be a higher compression and friction between the femoral fragments, which counteracts the torsion. Therefore, it is unfounded to conclude that derotational DFOs can start with full weight bearing postoperatively since this just represents an effect of the experimental setting and is not transferable to clinical application.

Limitations

There are a few limitations in this study. Only one type of locking plate and one technique of osteotomy were used and investigated biomechanically. In terms of stabilization, however, different types of plates used in clinical practice are comparable to the here-tested plate with four angle-stable screws that were attached to both sides of the osteotomy, respectively. Further biomechanical studies must be performed to confirm the results and to investigate different techniques of osteotomies, for example, biplanar technique from the lateral aspect of the distal femur according to the technique of Hinterwimmer et al. [10]. Obviously, the additional contralateral stabilization requires an

additional surgical approach with its own side-effects and risks, which were not further discussed in this biomechanical setup. Moreover, in this experimental setup, only axial and torsional load was simulated assuming that these were the most relevant forces on the osteotomy. Nevertheless, it remains an artificial setup, and the complex forces affecting an osteotomy in vivo cannot be mimicked completely. There was a wide range regarding the age of the donors from whom the specimens used in the current study were obtained. To reduce the influence of the different ages and to control for bias due to different bone quality, the specimens were distributed equally to the different groups according to the results of the bone density measurements.

CONCLUSION

The biomechanical investigation showed that the stabilization with a contralateral plate in addition to the angle-stable internal plate fixator provided superior stability in derotational DFOs compared to an angle-stable plate alone or an additional hinge screw. Most of the differences between the groups in terms of micromovements between the proximal and distal femoral fragments were found when torsional load was applied at partial weight bearing.

AUTHOR CONTRIBUTIONS

Felix Ferner: Writing/editing. Nele Hammersdorfer: Data curation, project administration, editing. Jessica Hembus: Biomechanical investigations, validation. Jan-Oliver Saß: Biomechanical investigations, validation. Rainer Bader: Biomechanical investigations, resources. Annett Klinder: Statistical analysis, language editing. Laura Hiepe: Anatomical preparation. Norman Holl: Statistical analysis, measurement of bone mineral density. Christoph Lutter: Original draft preparation/editing/supervision. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author (FF).

ETHICS STATEMENT

A2020-0098 (University Medical Center Rostock).
Informed consent is not applicable.

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Intraoperative control by Schanz-screws is inaccurate to achieve the exact amount of correction in de-rotational osteotomies

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Abstract

Purpose The accuracy of intraoperative control of correction commonly is achieved by K-wires or Schanz-screws in combination with goniometer in de-rotational osteotomies. The purpose of this study is to investigate the accuracy of intraoperative torsional control in de-rotational femoral and tibial osteotomies. It is hypothesized, that intraoperative control by Schanz-screws and goniometer in de-rotational osteotomies around the knee is a safe and well predictable method to control the surgical torsional correction intraoperatively.

Methods 55 consecutive osteotomies around the knee joint were registered, 28 femoral and 27 tibial. The indication for osteotomy was femoral or tibial torsional deformity with the clinical occurrence of patellofemoral maltracking or PFI. Pre- and postoperative torsions were measured according to the method of Waidelich on computed tomography (CT) scan. The scheduled value of torsional correction was defined by the surgeon preoperatively. Intraoperative control of torsional correction was achieved by 5 mm-Schanz-screws and goniometer. The measured values of torsional CT scan were compared to the preoperative defined and intended values and deviation was calculated separately for femoral and tibial osteotomies.

Results The surgeon's intraoperative measured mean value of correction in all osteotomies was 15.2° (SD 4.6; range 10–27), whereas the postoperatively measured mean value on CT scan was 15.6 (6.8; 5.0–28.5). Intraoperatively the femoral mean value measured 17.9° (4.9; 10–27) and 12.4° (1.9; 10–15) for the tibia. Postoperatively the mean value for femoral correction was 19.8 (5.5; 9.0–28.5) and 11.3 (5.0; 5.0–26.0) for tibial correction. When considering a deviation of plus or minus 3° to be acceptable femorally 15 osteotomies (53.6%) and tibially 14 osteotomies (51.9%) fell within these limits. Nine femoral cases (32.1%) were overcorrected, four cases undercorrected (14.3%). Four tibial cases of overcorrection (14.8%) and 9 tibial cases of undercorrection (33.3%) were observed. However, the observed difference between femur and tibia regarding the distribution of cases between the three groups did not reach significance. Moreover, there was no correlation between the extent of correction and the deviation from the intended result.

Conclusion The use of Schanz-screws and goniometer in de-rotational osteotomies as an intraoperative control of correction is an inaccurate method. Every surgeon performing derotational osteotomies must consider this and include postoperative torsional measurement in his postoperative algorithm until new tools or devices are available to guarantee a better intraoperative accuracy of torsional correction.

Study design Observational study.

Level of evidence III.

Keywords Knee osteotomy · Patellofemoral instability · De-rotational osteotomy · Intraoperative measurement

Introduction

Patellofemoral instability (PFI), anterior knee pain due to patellofemoral maltracking and posttraumatic torsional deformities are the most common indication for torsional

(= de-rotational) corrections around the knee joint [8, 10, 25, 31]. In cases of PFI, a combination of bony deformities is common: dysplasia of the trochlea, lateralization of the tibial tubercle, patella alta or torsional deformity of the femur, the tibia or both [5, 7, 14, 26]. Correction of the bony deformity is the causal therapy to avoid recurrent patella-dislocation or patellofemoral joint damage. This includes

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either trochleoplasty, medialization/distalization of the tibial tubercle or de-rotational osteotomy or a combination of techniques if necessary [6, 7, 16, 17, 19]. An increased femoral internal or external tibial torsion or its combination may also lead to patellofemoral maltracking and cause anterior knee pain [4]. It can be treated operatively by de-rotational osteotomy [10].

Complete long leg analysis is mandatory and includes clinical investigation of the frontal, sagittal and axial plane [23]. The axial plane must be investigated by torsional measurement. The method for the measurement of femoral and tibial torsion must be consistent; hereby, the technique according to Waidelich on CT scans is well described and established [30]. Operative technique and stabilization differ, but each technique requires an intraoperative control of the achieved torsional correction. Some authors describe K-wires [20] or Steinmann-Pins [1], some use Schanz-screws. Due to radiation exposure postoperative torsional control by CT scan is not performed in most of the (young) patients.

The main goal of the study was to deliver the missing proof in the current literature about derotational osteotomies and to investigate the accuracy of intraoperative torsional control by Schanz-screws and goniometer according to the technique described by Strecker [28]. It is hypothesized that this surgical technique is an accurate tool to control and achieve the planned amount of correction in derotational osteotomies and postoperative control by torsional CT scan can be disclaimed.

Materials and methods

Inclusion and exclusion criteria

Between 01/2018 and 10/2021, all de-rotational osteotomies around the knee joint that matched the inclusion and exclusion criteria were registered. Inclusion criteria were PFI or anterior knee pain due to patellofemoral maltracking in patients with a femoral or tibial torsional deformity and failure of conservative treatment. Exclusion criteria were patients with a history of previous operations, dysplasia of the trochlea type D, follow-up less than 6 months and a varus or valgus deformity ($> 3^\circ$).

Preoperative radiographic analysis included full weight-bearing long leg radiographs and torsional CT scan according to the protocol of Waidelich [30]. The value of the intended correction was determined and documented preoperatively by the surgeon. The torsional angle was not always aimed to be the “normal mean value” defined by Strecker et al. (femoral -24° and $+34^\circ$ tibial) but was influenced by different other factors such as contralateral torsion, amount of correction and additional deformities [29].

Surgical technique and postoperative treatment

Torsional correction was performed after arthroscopy of the knee joint to detect and treat intraarticular pathologies [21]. Tibial osteotomy was performed according to the technique of Strecker [28]. It was executed from the lateral aspect of the tibial head biplanar with the main osteotomy metaphyseally parallel to the joint line and the oblique cut proximal to the tibial tubercle. The femoral osteotomy was performed according to the protocol of Dickschas from the medial aspect of the femur uniplanar with the osteotomy 90° to the mechanical axis of the femur to avoid undesired side effects in the sagittal or frontal plane [9]. In both techniques two 5-mm-Schanz-screws proximal and distal of the osteotomy were placed prior to the osteotomy to monitor the torsion of the fragments intraoperatively. The Schanz-screws were placed in the angle of the desired correction; this angle was adjusted by a goniometer (Fig. 1). After the osteotomy the two Schanz-screws were parallelized, and stabilization was obtained by plate. An intraoperative image-intensifier documented the bony correction and finally, before removal of the Schanz-screws, its parallel position was checked clinically. Femoral fixation was achieved by an internal angle stable plate (Tomofix Medial Distal Femur, DePuy Synthes, West Chester, Pennsylvania, USA), tibial an individually bended 5-whole DC-plate (DePuy Synthes, West Chester, Pennsylvania, USA) was used.

Postoperatively X-ray of the knee joint in two planes (anterior–posterior and lateral view) were obtained (Fig. 2). All osteotomies were performed inpatient by two of the authors. Postoperative treatment included 20 kg partial

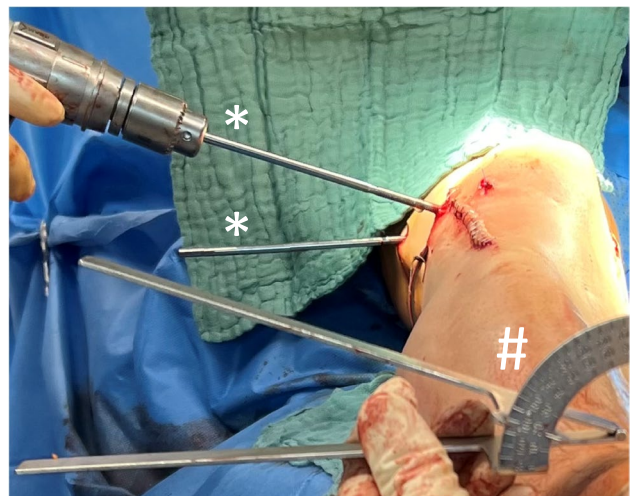
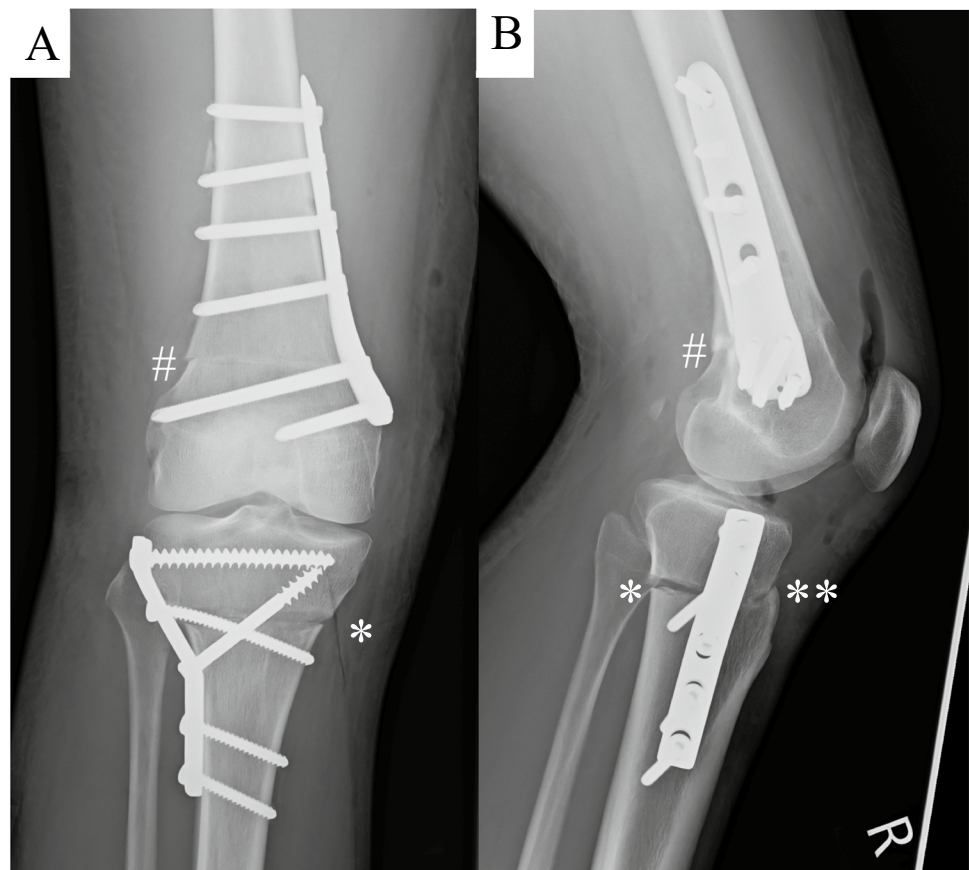


Fig. 1 5 mm-Schanz-screws (*) are placed in the proximal and distal fragment prior to the femoral de-rotational osteotomy angulated with the intended correction angle. The angle is measured by a goniometer (#) intraoperatively from an axial perspective

Fig. 2 The radiographs of the knee joint in the ap (A) and lateral (B) view are depicting the postoperative situation after double level torsional osteotomy. Femorally an uniplanar osteotomy (#) was executed and the fixation was achieved by an angle stable plate fixateur. Tibially a biplanar osteotomy (*) parallel to the plane of the knee joint and second cut (***) superior to the tibial tubercle. The tibial fixation is obtained by an individually bended 5-whole DC-plate



weight bearing for 6 weeks on crutches and free range of motion. Torsional CT scan was performed postoperatively before patient was discharged.

Measurement of torsional correction

Femoral and tibial torsion was measured on CT scan pre- and postoperatively (Fig. 3) via digital planning software (Medicad Hectec GmbH, Altdorf, Germany) according to the method of Waidelich [30]. Intra- and inter-observer reliability was calculated using the interclass correlation coefficient. Two individual board-certified orthopaedic surgeons independently reviewed and measured all CT scans at different time points. For intra-rater variability, one reviewer repeated all measurements.

The difference between pre- and postoperative values was calculated and compared to the preoperative determined (intended) value. A power calculation was performed in SPSS 28.0 (IBM Germany GmbH, Ehningen) for the hypothesis that the actual torsional correction should correlate significantly with the intended torsional correction if the surgical technique by Strecker is an accurate tool to achieve the planned amount of correction. Sample

size was estimated for one-sample Spearman rank-order test with Fisher's asymptotic method, as patient data are often not normally distributed. Based on a power of 0.8, a significance level of 0.05 in a two-sided test and an intermediate to strong correlation value of 0.7 with 0.25 as value of the confidence interval half-width, a sample size of 25 pairs (actual/intended) was calculated.

Statistical analysis and visualization of data were performed by GraphPadPRISM v.9.2 (GraphPad Inc., San Diego, CA, USA). Goniometer values were reported to an accuracy of 1°, while CT values were rounded to the nearest 0.5°. Depending on a normal distribution either Pearson r coefficient or Spearman r_s coefficient were used to assess correlation between the intended and actual torsional correction. The strength of the effect was graded according to Cohen (1992), who classified $r \geq 0.10$ as a weak effect, $r \geq 0.30$ as a moderate effect and $r \geq 0.50$ as a strong effect. [3] Bland–Altman plots visualize the agreement between the intended and actual torsional correction by plotting the deviation between the two measurements. When both measurements are the same, the plotted value is zero. The more both measurements differ, the greater the distance from the zero line.

Fig. 3 Femoral and tibial torsion is measured according to the method of Waidelich using digital planning software. The femoral angle (α) consists of the line (a) between the midpoint of the femoral head (A) and an ellipse within the greater trochanter proximally (B) and a tangent (b) to the femoral condyles distally (C). Tibial torsion (β) is measured between a tangent (c) to the tibial plateau proximally (D), and a connecting line (d) between the midpoint of ventral and dorsal point of incisura malleoli laterally and midpoint of medial malleolus medially (E). In this case femoral torsion α measures -18° and tibial torsion $+40^\circ$ according to the method of Waidelich

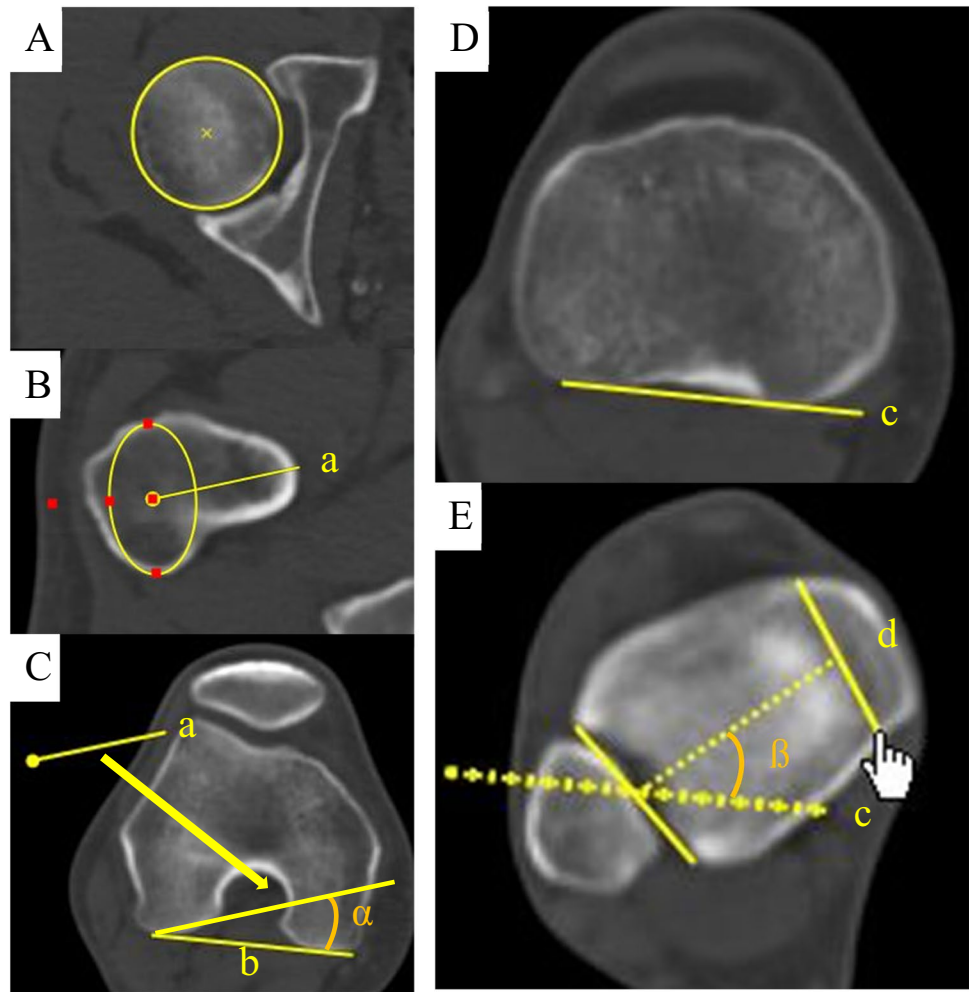


Table 1 Summary of results

	Intraoperative angle in $^\circ$ MV (SD; range)	Postoperative angle in $^\circ$ MV (SD; range)
Femoral and tibial OT	15.2 (4.6; 10–27)	15.6 (6.8; 5.0–28.5)
Femoral OT	17.9 (4.9; 10–27)	19.8 (5.5; 9.0–28.5)
Tibial OT	12.4 (1.9; 10–15)	11.3 (5.0; 5.0–26.0)

OT osteotomies; MV mean value; SD standard deviation

Results

55 osteotomies involving 42 patients were included in this observational cohort study, 32 female and 10 male subjects. The mean age at the time of osteotomy was 25.9 years (SD 9.1; range 14–57); the mean value for body-mass-index (BMI) was 23.3 kg/m² (SD 3.9; range 16–35). 28 femoral and 27 tibial osteotomies were registered.

The measurements for the intraoperative values are listed in Table 1 (first column). These values were

measured and documented by the surgeon intraoperatively. They are divided into three groups: all osteotomies, femoral, and tibial osteotomies. The values in the next column of Table 1 represent the correction angles measured by CT scan. While there were significant correlations between the actually measured and the intended angles for all osteotomies as well as the femoral and tibial osteotomies alone (Fig. 4), partly high differences between the actual and intended values were observed. For all osteotomies on average a difference of 3.8° (3.4; 0–12.5) was found between the surgeon's intraoperative measured angle and the achieved angle of correction measured on postoperative CT scan. In femoral osteotomies the mean difference between intraoperative measured angle and the postoperatively calculated angle was 4.1° (3.9; 0–12.5), while in tibial osteotomies the intraoperative measured angle differed on average by 3.5° (2.8; 0–11) from the angle in the CT scan. The difference between intraoperatively measured and postoperatively calculated angles is visualized for every single pair of values in Bland–Altman plots (Fig. 5). The difference between the actual and the intended result

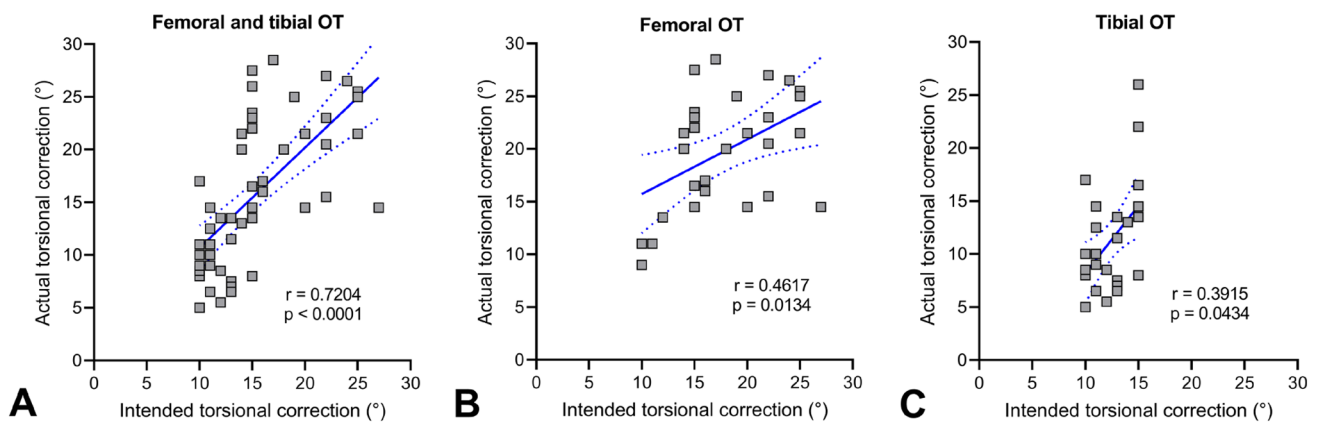


Fig. 4 Significant correlation between the actually measured correction and the intended angles for all osteotomies (A) as well as the femoral (B) and tibial osteotomies (C). Correlation analysis was performed according to Pearson (B) or Spearman (A and C) depending on normal distribution of values. While there was a strong correla-

tion when analyzing all OTs ($r=0.720$, 95% CI 0.557–0.830), only moderate correlations were observed for femoral and tibial OTs alone ($r=0.462$, 95% CI 0.107–0.712 and $r=0.392$, 95% CI 0.002–0.678, respectively); $p < 0.05$ was considered significant. OT osteotomies

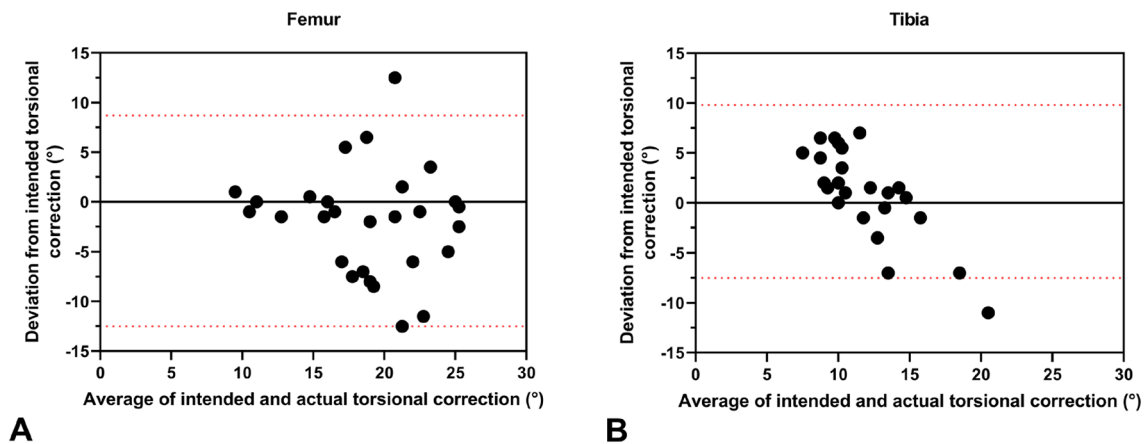


Fig. 5 Difference between the pairs of values for the actually measured correction and the intended angles. The agreement between actual and intended torsional correction is illustrated by the Bland–

Altman plots (A, B). Red-dotted line is depicting the 95%—limits of agreement. Only in a few cases, the actual torsional correction corresponded exactly with the intended torsional correction (zero value)

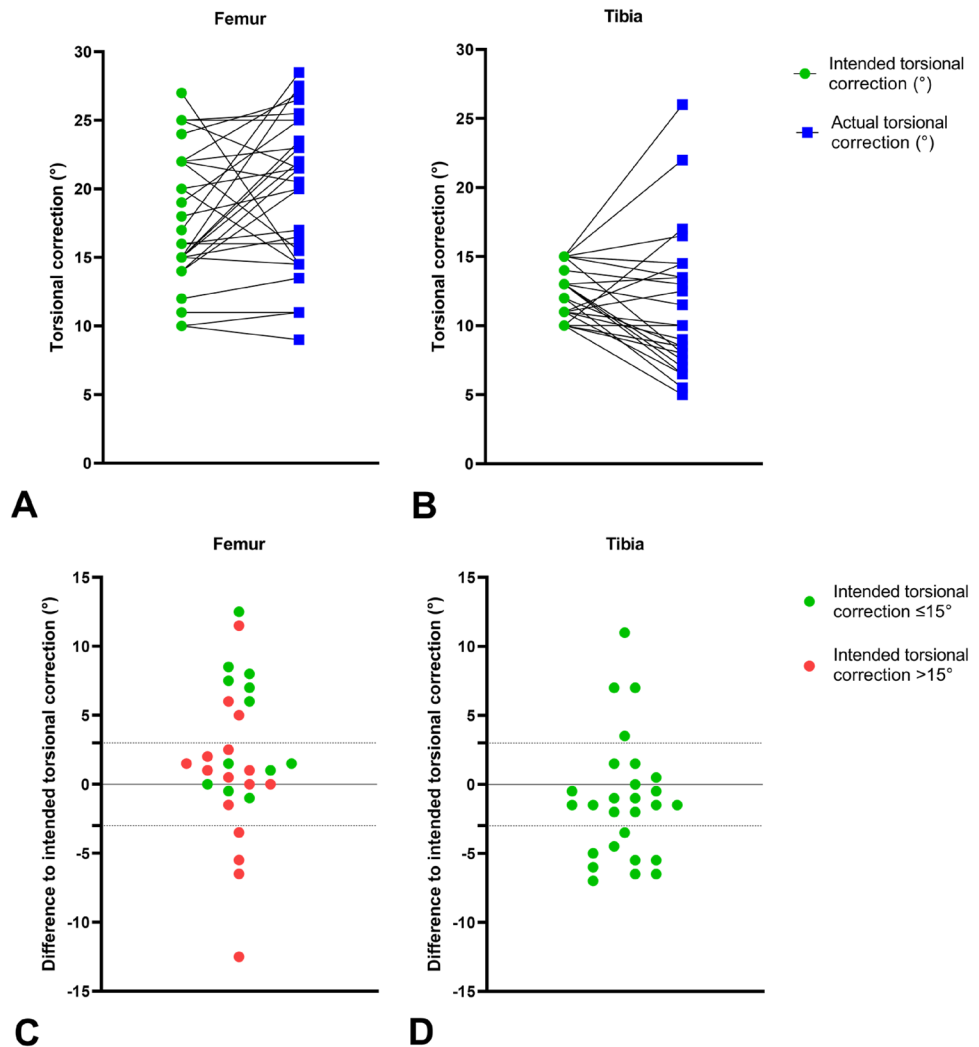
did not correlate to the extent of the intended correction (Spearman’s correlation: femur $r=0.04$ (95% CI -0.350 to 0.415), p -value n.s.; tibia $r=0.08$ (95% CI -0.321 to 0.455), p -value n.s.), which indicates, that surgeries for correcting larger torsional angles were not associated with less favourable outcomes than surgeries with small angles.

A deviation of $\pm 3^\circ$ from the surgeon’s intraoperatively determined angle of correction was considered acceptable. Overall, 29 osteotomies out of 55 osteotomies (52.7%) were inside this threshold of 3° with 15 femoral and 14 tibial osteotomies (Fig. 6). Vice versa 13 out of 28 (46.4%) femoral osteotomies and 13 out of 27 (48.1%) tibial osteotomies dropped out of this 3° -limit, which indicates that almost every second osteotomy (47.4%) deviated more

than 3° from the intraoperative measured angle. It was observed, that for the femur cases outside the 3° -limit tended to be overcorrected with nine cases (32.1%) compared to 4 undercorrected femoral cases (14.3%) (Fig. 6A, C), while for the tibia cases were rather undercorrected (overcorrected $N=4$ [14.8%] vs undercorrected $N=9$ [33.3%]) (Fig. 6B, D). However, the observed difference between femur and tibia regarding the distribution of cases between the three groups (undercorrected, corrected and overcorrected) did not reach significance (Chi square, p -value n.s.).

This study was conducted in accordance with the 1964 Helsinki Declaration and approved by the ethical board of the university (ethical board number 69_19 B).

Fig. 6 Comparison of femur (A, C) and tibia (B, D) regarding the differences between the actual and intended torsional corrections. When considering a deviation of plus or minus 3° (dotted lines in C and D) to be acceptable, only slightly more than every second correction fell within these limits (femur 53.6%; $N=15$ and tibia 51.9%; $N=14$). Femur cases outside the 3°-limit tended to be overcorrected with nine cases (32.1%) compared to 4 undercorrected cases (14.3%) (A, C), while for the tibia cases were rather undercorrected (overcorrected $N=4$ [14.8%] vs undercorrected $N=9$ [33.3%] (B, D)



Intra- and inter-observer reliability

We classified repeatability as excellent ($R > 0.90$), good ($R > 0.75$), or poor to moderate ($R < 0.75$), as defined by Portney and Watkins. Intra-rater reliability was excellent ($R = 0.985$, $CI = 0.973$) while inter-rater reliability was good ($R = 0.846$, $CI = 0.738$). Therefore, the measurement methods themselves were considered reliable [24].

Discussion

The most important finding of this study is that 47.4% of the registered osteotomies (26 out of 55) dropped out of the 3°-limit, which was considered as tolerable. Hence, almost every second de-rotational osteotomy is not exact. Therefore, the intraoperative method of measurement by Schanz-screws and goniometer is not accurate to achieve the desired amount of correction in de-rotational osteotomies of the knee. The limit of 3° was set by the authors, there is no evidence that

clinical outcome is worse with a deviation of more than 3°. It has been shown previously that functional scores, pain level and patella stability can be improved by de-rotational osteotomies of the femur and tibia [2, 8, 10, 11, 13, 18, 31]. A comparison between the intended amount of correction and the achieved correction is missing in the current literature. Hinze et al. reported about a reduction of the femoral torsion from $28.2^\circ \pm 6.4^\circ$ preoperative to $13.6^\circ \pm 5.2^\circ$ with a different method of measurement according to Schneider [11, 27]. In their cohort the indication for femoral osteotomy was set with a femoral torsion $> 20^\circ$ (physiological femoral torsion according to Schneider 10.4°). It was not mentioned in the manuscript which was the surgeon's intended value of correction. Imhoff et al. reported that 13% of the patients (5 of 42 patients) were not satisfied with the result of the femoral de-rotational osteotomy at a 4-year-follow-up period without giving a reason for dissatisfaction. It may be speculated that in the cited study with a similar operative technique the accuracy of intended correction may be similar to the findings of the current study. An analysis of the

“not-satisfied” patients after de-rotational osteotomies and a correlation to clinical scores must be obtained in the future. Despite the missing clinical evidence for the 3°-limit a high accuracy and reliability in torsional osteotomies should be the surgeon’s claim.

The results demonstrated a tendency to femoral overcorrection and tibial undercorrection. This may be explained by a loss of correction due to the different fixation methods. Moreover, tibial the additional “fixation” by the fibula may play a role for the tendency to undercorrection.

As it was shown by Strecker et al. the physiological mean value for the femoral and tibial torsion shows a very high intra-individual variation (13° femoral, 14° for tibial) [29]. This high variation may influence the demand for an exact intraoperative measurement. Nevertheless, an accuracy of $\pm 3^\circ$ seems to be a sufficient surgical goal assuming a mean correction of 15.9°.

In some institutions CT scan is replaced by MRI, which is obviously without radiation exposure, but as it takes longer, it is prone for movement of the patient, and consecutively may be more inaccurate. If operative technique including intraoperative measurement of correction was correct, no postoperative torsional measurement is necessary, no matter which technique is used. This reduces either radiation exposure of the young patients or at least is more cost-effective.

In times of digitalization of the operating theatre, at least a more reliable method of measuring the angle of the Schanz-screws should be realized soon. Another opportunity of achieving a higher reliability in (de-rotational) osteotomies could be the application of (patient specific instruments (PSI). If the osteotomy level deviates from the 90°-axis to the mechanical axis, a “single-cut-osteotomy” is performed with undesired side-effects in all dimensions [12, 15, 22].

Limitations

No clinical scores were obtained in this study, which would have been interesting especially in the patients, who fell out of the 3°-limit. Double level de-rotational osteotomies were not excluded in this study since both femoral and tibial osteotomy and its intraoperative measurement of torsion are executed separately. Pre- and postoperative torsional measurements according to the described method were independent as well. Therefore, double-level-osteotomies could be included and did not influence the results of the study. The number of cases is relatively low with 28 femoral and 27 tibial osteotomies, whereas the method of intraoperative measurement in both osteotomies is equal. Of course, further studies with a higher number of cases should be conducted in the future.

Measurement of torsions of the lower limb by CT or MRI is a method prone to mistakes, which may lead to a poor reliability. Therefore, setting must be approved in each institute

for reliable results. The Waidelich-method is described for an analogue measurement [30]. In current practice as well as in this study, the measurement was obtained by digital software. Evidence about the reliability for this method is missing so far in the current literature. Therefore, intra- and inter-observer reliability was calculated and showed a good to excellent reproducibility of the digital method.

Conclusion

The intraoperative torsional control by Schanz-screws and goniometer in de-rotational osteotomies of the knee joint is not a reliable and well predictable method in terms of achieving the intended amount of correction. Hence, postoperative torsional measurement is needed until new methods of intraoperative control of torsional correction are available with a better reliability.

Declarations

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Conflict of interest The authors declare that they have no potential conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in this study.

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Correction of tibial tubercle trochlea groove distance is related to torsional correction in high tibial derotational osteotomy

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Abstract

Purpose High tibial osteotomy with internal tibial derotation (high tibial derotation osteotomy = HTDRO) is a common surgical treatment in patients with patellofemoral malalignment alone or in combination with patellofemoral instability. Operative techniques and theoretical calculations may assume that correction of the tibial tubercle-trochlear groove (TTTG) distance is related to the amount of torsional correction. The purpose of this investigation was to predict the change in TTTG distance in HTDRO through a clinical study.

Methods Twenty-one consecutive cases of derotational HTO were evaluated by torsional CT scanning in terms of the pre- and postoperative tibial torsion and TTTG distance. Changes in the TTTG distance were related to the changes in the amount of torsional correction. The change in patellar height was measured pre- and postoperatively, and the Caton–Deschamps Index (CDI) was calculated.

Results The mean change in tibial torsion was 13.9°, and the mean change in the TTTG distance was 6.3 mm. A strong relationship (0.90) between the change in torsion and the change in TTTG distance from pre- to postoperative status was found ($p < 0.001$). No statistically significant change in CDI could be seen between the preoperative [mean value (MV) 1.0] and postoperative (MV 1.1) periods.

Conclusions In patients with patellofemoral instability or patellofemoral maltracking with both a high tibial external torsion and a high TTTG distance, a derotational HTO can correct both bony deformities. Patella height does not change significantly with this surgical technique. With 1° of torsional correction, the TTTG distance decreases 0.45 mm with our surgical technique of derotational HTO.

Keywords Knee · High tibial osteotomy · Derotational osteotomy · TTTG distance · Patellofemoral instability

Introduction

Patellofemoral instability (PFI) and anterior knee pain caused by patellofemoral malalignment are multifactorial disorders that require a comprehensive analysis of the patellofemoral joint. Common classifications [2, 12] consider bony deformities such as dysplasia of the trochlea, femoro-tibial valgus deformity, torsional deformity of the femur

or tibia, or lateralization or proximalization (patella alta) of the tibial tubercle [6, 8, 14, 16, 17]. Frequently, several combined bony deformities cause PFI or patellofemoral maltracking and the surgeon is faced with the question of which deformity must be corrected. In patients with increased tibial external torsion, a torsional osteotomy is needed [7, 22], whereas tibial tubercle osteotomy is the treatment of choice in patients with lateralization of the tibial tubercle [13]. Jud et al. [15] proved in a simulation that correction of the tibial tubercle trochlea groove (TTTG) distance can be predicted by the degree of torsional correction. It has not been shown in a clinical study that improvement of tibial rotation and TTTG distance can be achieved by a high tibial osteotomy with internal derotation and an osteotomy level proximal to the tibial tubercle.

The purpose of this study was to predict the amount of correction of the TTTG distance in patients with derotational

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HTO. The hypothesis of this publication is, that in patients with high tibial osteotomy (HTO) with internal derotation the correction of the TTTG distance can be calculated preoperatively and is related to the degree of rotational correction, which has not been shown in the current literature.

Materials and methods

Between 07/2018 and 05/2021, all consecutive cases with derotational HTO in one institution were registered. This study was approved by the ethical board of the university. The exclusion criteria were double-level osteotomy (additional femoral torsional osteotomy or trochleaplasty) and more than three degrees of femorotibial mechanical varus or valgus. The indication for osteotomy was increased external tibial torsion based on the normal value of $+34^\circ$ degrees [28] in patients with patellofemoral instability or anterior knee pain with patellofemoral maltracking in accordance with increased clinical external tibial torsion. Clinical investigation of the range of tibial internal and external torsion was performed by resting the foot

with position dorsal extension of the ankle joint and the patient in a supine position. Hence, applying the inclusion and exclusion criteria, 21 osteotomies in 19 patients were included in this study.

Radiological evaluation

All patients were investigated according to the same radiological protocol: X-ray of the knee joint in two planes and CT scan pre- and postoperatively. Evaluation of the frontal plane was obtained on a full weight-bearing long leg X-ray preoperatively. Postoperative X-ray and CT scans were performed before discharge of the patient. CT scans were evaluated according to the method of Waidelich [29] with 3D software (Medicad Hectec GmbH, Altdorf, Germany). Torsional and TTTG measurements are shown in Fig. 1.

The change in tibial torsion and the TTTG distance from pre- to postoperative status was calculated. The patella height was measured on a lateral view X-ray of the knee joint pre- and postoperatively, as shown in Fig. 2, and the Caton–Deschamps Index (CDI) [5] was calculated.

Fig. 1 **A** Measurement of tibial torsion according to the method of Waidelich [27]. Total tibial torsion is an angle (*) between the tangent of dorsal tibial head proximally (a) and midpoint between ventral and dorsal point of incisura malleoli laterally and medial malleolus medially (b). **B** TTTG distance ($\#$) is measured between the distance of deepest point of femoral trochlea proximally (d) and midpoint of tibial tubercle distally (e) using a tangent to the dorsal femoral condyles as a reference

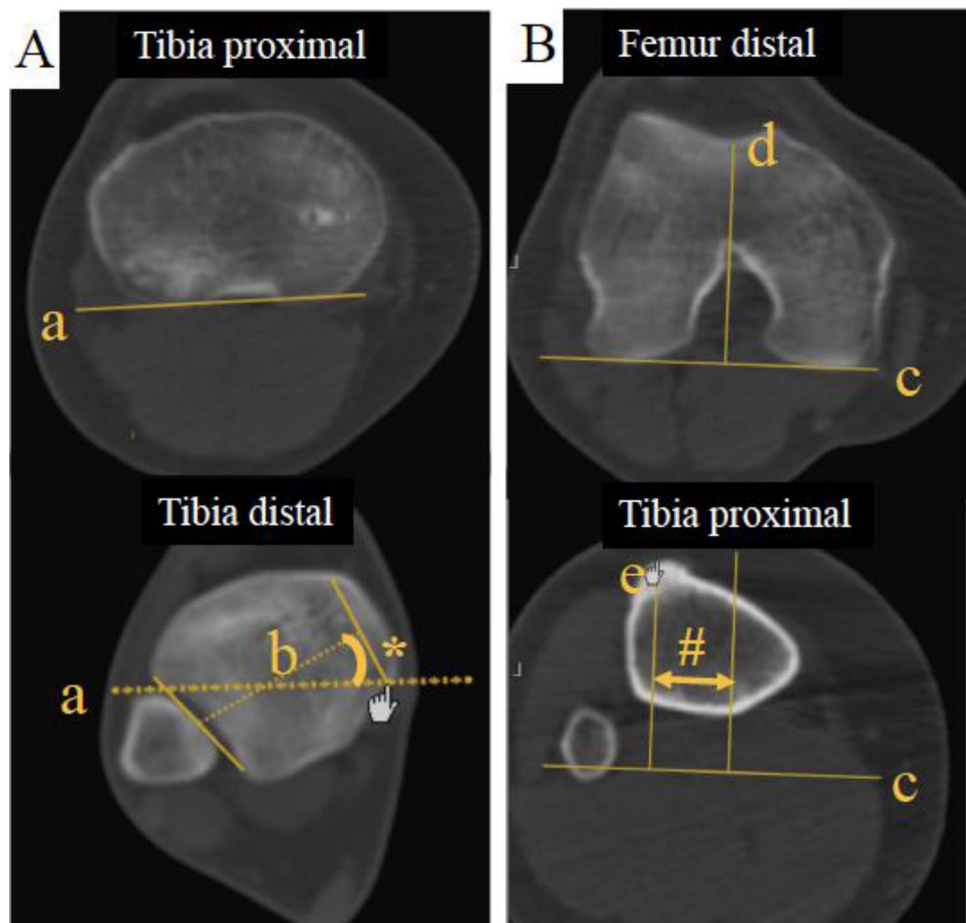
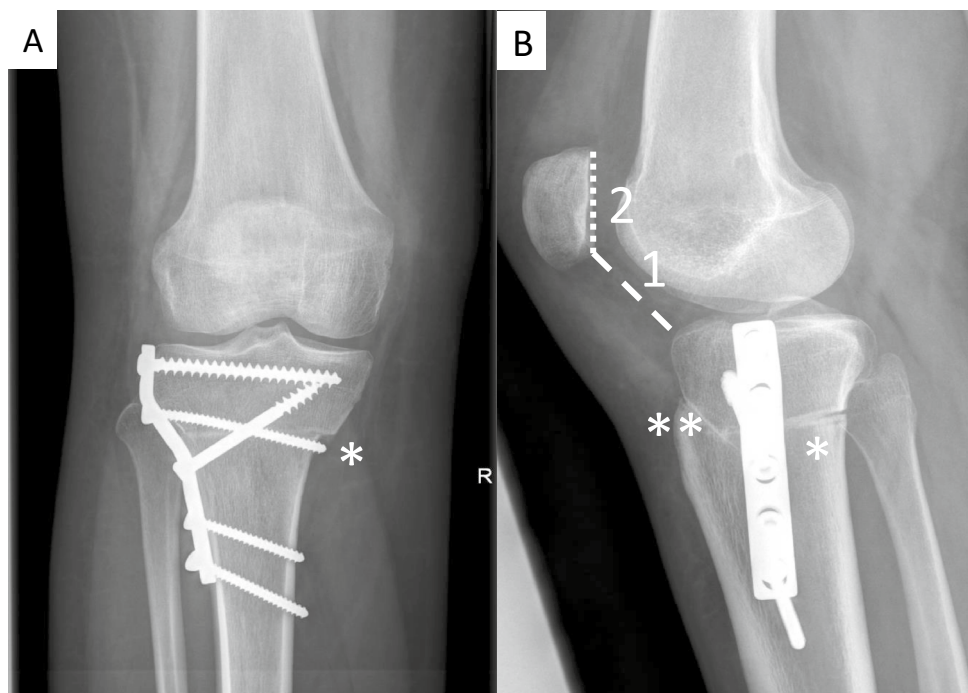


Fig. 2 Postoperative X-ray in anterior–posterior view (A) and lateral (B) view depicting biplanar osteotomy with main osteotomy plane* with a 90°-angle to mechanical axis of the tibia and oblique cut above the tibial tubercle**. Five screws were placed in the same position and quality (from proximally to distally): one spongiosa screw, one cortical screw, one partial spongiosa screw and two cortical screws. Caton–Deschamps index for evaluation of patella height is calculated by the ratio of distance 1 and 2 in lateral view (B)



Surgical procedure

All patients were operated on by two surgeons (the first and senior authors) following the same protocol [26]. Osteotomy was performed biplanarly with the oblique cut ending proximal to the tibial tubercle using a lateral approach to the proximal tibia. Osteosynthesis was performed with an individual bent 5-hole DC plate (DePuy Synthes, West Chester, Pennsylvania, USA) (Fig. 2). Torsional correction was controlled intraoperatively with 5 mm Schanz screws. In patients with a correction angle of more than 15 degrees, neurolysis of the peroneal nerve and fasciotomy of the tibialis anterior muscle were performed. In cases with PFI, additional reconstruction of the medial patellofemoral ligament (MPFL) according to the technique of Fink et al. [10] was executed.

Statistical analysis

Measurements of tibial torsion, TTTG distance and CDI pre- and postoperatively were obtained by two independent observers. Microsoft Excel (Microsoft, Redmond, Washington, USA) was used for data collection; statistical analyses were performed using SigmaStat software (Systat Software Inc., San Jose, USA) and SPSS version 24 (SPSS Inc. Chicago, Illinois). Values were checked for normality with the Shapiro–Wilk test. To determine the difference among groups, a *t* test or rank sum test was used depending on the normal distribution. The change in tibial torsion was correlated with the change in TTTG distance using Pearson Product Moment Correlation. Inter- and intrarater reliability

was calculated using the intraclass correlation coefficient for continuous data [20]. Unless stated otherwise, data are expressed as the mean and standard deviation with range, as appropriate. *p* values less than 0.05 were considered statistically significant.

Results

Twenty-one osteotomies in 19 patients (12 females, 7 males) were included in this retrospective study. The mean age at operation was 24 ± 6.3 (17–38) years. The mean preoperative tibial torsion angle was $46.2^\circ \pm 4.3$ (41.8–55.9), and $32.3^\circ \pm 5.5$ (31.6–44.2) postoperatively; the mean preoperative TTTG distance was $15.7 \text{ mm} \pm 3.7$ (12.7–24.8) and $9.4 \text{ mm} \pm 3.5$ (6.5–15.7) postoperatively. This results in a mean correction angle of $13.9^\circ \pm 4.2$ (8.2–21.3) measuring tibial torsion and $6.3 \text{ mm} \pm 1.6$ (2.8–9.9) in terms of the TTTG distance (Table 1).

Statistical analysis revealed a strong positive correlation ($R=0.902$) between the change in tibial torsion and the TTTG distance from the pre- to the postoperative period ($p < 0.001$). (Fig. 3).

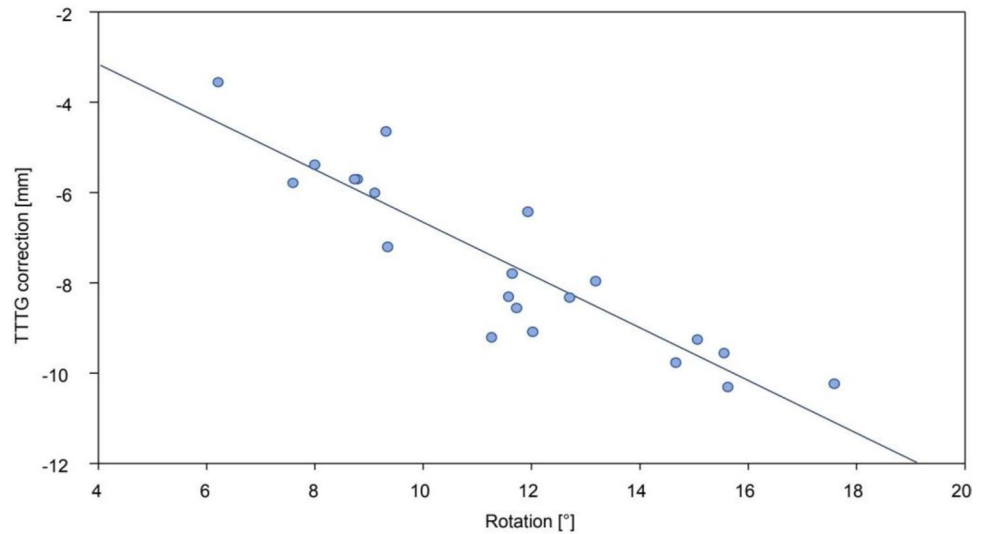
Hence, with 1° of torsional correction the TTTG distance decreases by 0.45 mm on average with this surgical technique.

The mean preoperative CDI was 1.0 ± 0.2 (0.8–1.5), and the mean postoperative CDI was 1.1 ± 0.2 (0.8–1.4). The paired *t* test showed no statistically significant change in CDI from pre- to postoperatively ($p = 0.545$). Thus, no

Table 1 Measurement of tibial torsion, TTTG distance, and CDI

	Preoperative MV (SD; range)	Postoperative MV (SD; range)
Tibial torsion in degree	46.2 (4.3; 41.8–55.9)	32.3 (5.5; 31.6–44.2)
TTTG distance in mm	15.7 (3.7; 12.7–24.8)	9.4 (3.5; 6.5–15.7)
Caton–Deschamps index	1.0* (0.2; 0.8–1.5)	1.1* (0.2; 0.8–1.4)

*Indicates no statistically significant difference using paired *t* test ($p=0.545$)

Fig. 3 Graph depicting strong correlation ($R=0.902$) between change of tibial torsion (horizontal axis) and TTTG distance (vertical axis) from pre- to postoperatively**Table 2** Intra- and inter-rater reliability [20]

	Intra-rater reliability	Inter-rater reliability
Tibial torsion preop.	0.992	0.936
Tibial torsion postop.	0.994	0.827
Change of tibial torsion	0.989	0.830
TTTG preop.	0.997	0.950
TTTG postop.	0.996	0.973
Change of TTTG	0.985	0.823

preop. preoperative, postop. postoperative

significant change in patella height was observed by this type of osteotomy.

All values (tibial torsion pre- and postoperatively, change in tibial torsion, TTTG distance pre- and postoperatively, change in TTTG) of the male and female patients were compared, and no statistically significant difference was observed ($p > 0.05$), apart from the postoperative TTTG, which was slightly higher in males ($p = 0.046$). Thus, no difference between male and female patients was found in this study group.

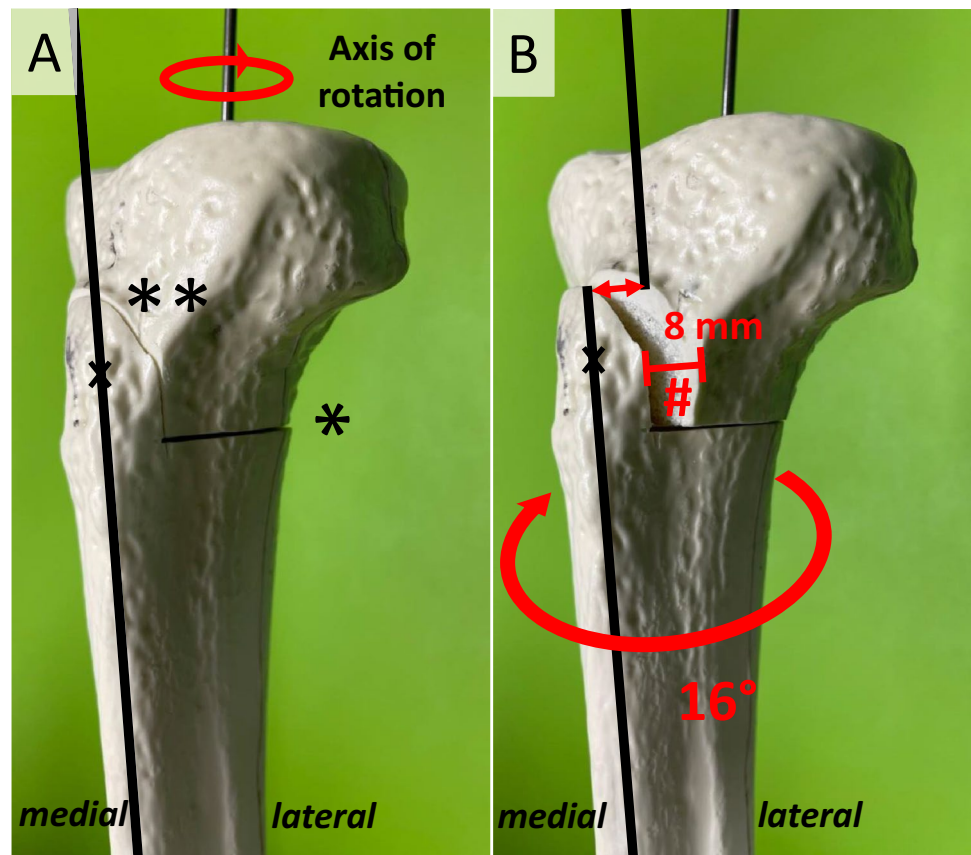
Intra/interrater reliability

There was excellent intra- and interrater reliability. Consequently, the measurement methods were considered reliable [20]. All reliabilities are presented in Table 2.

Discussion

The most important finding of this clinical study was that in high tibial derotational osteotomies, the decrease in TTTG distance is related to the change in internal rotation. The main goal of this study was to provide the clinical proof of the theoretical construct of Jud et al. [15]. He showed in a 3D model that high tibial derotational osteotomies lead to a change in the TTTG distance. With the oblique cut of the osteotomy ending proximal to the tibial tubercle [26], it is possible to predict the change in TTTG distance depending on the torsional correction (Fig. 4). Hence, TTTG distance and tibial torsion can be corrected with one osteotomy, which is a valuable fact in patients with PFI or patellofemoral maltracking. In most of these patients, the surgeon is confronted with a multifactorial problem, and frequently, several surgical procedures must be combined [11, 21, 27]. The demonstrated technique can be easily combined with femoral torsional osteotomy, MPFL reconstruction, lateral release and/or trochleoplasty.

Fig. 4 **A** Proximal tibia (without fibula) with the two planes of the osteotomy, which must be executed correctly to avoid undesired effects. Main osteotomy (*) 90° to the mechanical axis of the tibia in the frontal plane and parallel to the tibial plateau in the lateral view. Second osteotomy (***) proximal to the tibial tubercle. **B** By internal torsion of the distal fragment a small gap (#) is visible, which indicates the intended effect of this type of osteotomy with medialization of the tibial tubercle



Another issue of this multifactorial problem is patella alta as a known risk factor for PFI [1, 2, 25]. It could be proven in this study that with this surgical technique, the patella height does not change significantly, although there is a tendency for patella indices to slightly increase. In this cohort, four knees in three patients had a patella alta with a CDI value of more than 1.2 [4]. In two of them, the indication for osteotomy was patellofemoral maltracking and in the other patient indication was PFI for both sides. In all four cases increased tibial torsion was analysed as a more important risk factor than patella height [24].

Winkler et al. [29] recently investigated the location of tibial torsional deformity and stated that in his cohort of 24 patients with PFI, it was an infratuberositary deformity. He concluded that in these cases, increased tibial torsion did not correlate with increased lateralization of the tibial tubercle, which was confirmed by several different studies [3, 9]. One may assume that these results contradict the findings of the current study, but it must be recognized that in the current study, there was a bias of patient selection, since only patients who received a torsional osteotomy were included. The indication was set only in cases that may benefit from a supratuberositary torsional osteotomy, whereas

the amount of correction in this study was a minimum of 10 degrees. The *p* value for a significant correction in rotational osteotomies cannot be provided. The surgical goal for the postoperative angle is usually a normal value of 34 degrees (according to Waidelich). Only in cases with an excess external tibial torsion of 45 degrees or more preoperatively, the surgical goal is reduced by the surgeon when planning the osteotomy due to the risk of soft tissue problems (compartment syndrome, peroneal nerve palsy).

The mean TTTG distance preoperatively was relatively high (15.7 mm), assuming 10 ± 1 mm as a normal value [18]. In only six cases, the TTTG distance was less than 15 mm, but in all six cases, in the absence of other bony deformities, external tibial torsion was increased, and derotational HTO was indicated.

The change in TTTG distance was 0.68 mm per degree of rotational change in the simulation of Jud et al. [15]. In this clinical study, the change in TTTG distance measured 0.45 mm with each degree of torsional change. This difference between theoretical calculations and clinical results may be explained by the different axes of rotation in clinical application, where soft tissues (e.g. medial collateral ligament) and the fibula influence the rotation of fragments.

Clinical relevance

This study indicates that the change in TTTG distance can be reliably calculated preoperatively when planning an HTO with internal derotation. This is a valuable tool for the knee surgeon in the decision-making process regarding whether to perform a tibial tubercle osteotomy or an HTO with internal derotation. Comparing tibial torsional osteotomy and tibial tubercle osteotomy in patients with excess external tibial rotation, Paulos et al. [19] showed a better clinical outcome in the torsional osteotomy group.

Limitations

It can be concluded that only a low number of cases were investigated in the current study, and further studies with a higher number of cases must be obtained. Nevertheless, the findings of this study show that in cases with increased tibial torsion and TTTG distance, a supratuberositary osteotomy can address both deformities. The accuracy of transverse and tibial tubercle osteotomy is important because it strongly influences the postoperative axis in the frontal, sagittal and torsional dimensions (Fig. 4).

Measurement of the TTTG distance may be influenced by intraarticular rotation of the knee joint, which is eliminated when measuring the TTPCL distance [23]. However, intraarticular rotation is not influenced by torsional osteotomy. Consequently, the TTTG distance can be used as a value measuring the medialization of the tibial tubercle by derotational HTO. There is no common measurement that indicates ventralization of the tibial tubercle, which is one goal of derotational HTO or tibial tubercle osteotomy to release pressure from the patellofemoral joint.

Conclusion

This clinical study shows that with a derotational HTO, the TTTG distance and increased high tibial external torsion can be corrected simultaneously, whereas the patella height does not change significantly. The TTTG distance decreases by 0.45 mm with 1° of rotational correction via the surgical technique of biplanar osteotomy with an oblique cut proximal to the tibial tubercle.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Perioperative complications in osteotomies around the knee: a study in 858 cases

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Abstract

Introduction Eight hundred and fifty-eight consecutive osteotomies around the knee joint were analyzed retrospectively to detect intra- and early postoperative complications in a period of 4 weeks postoperative. Indications for osteotomy were unilateral gonarthrosis or torsional deformities resulting in femoropatellar instability or anterior knee pain.

Materials and methods Etiology of deformity, technique and mode of correction and level of osteotomy were registered. Complications were detected and divided in minor complication (superficial wound infection, and deep-vein thrombosis) and major complication (compartment syndrome, deep infection, and vascular lesion).

Results Fifteen major (1.7%) and 17 minor complications (2.0%) were detected: 5 vascular lesions (0.58%), 4 compartment syndromes (0.47%) and 6 deep infections (0.70%), 14 superficial wound infections (1.6%) and 3 deep-vein thrombosis (0.35%). In posttraumatic osteotomies and continuous corrections, risk for a superficial wound infection was significantly higher and with osteoclasis risk for vascular lesion was higher compared to osteotomy with oscillating saw. No difference was found for anatomical level of osteotomy and for the other complications in terms of etiology of deformity, technique of osteotomy and mode of correction.

Conclusion Osteotomy around the knee is a safe procedure in the treatment of unicompartmental gonarthrosis in terms of intra- and postoperative complications. Major complications are rare. Pit falls for compartment syndromes (LCW and torsional corrections) have to be kept in mind. There is no difference in frequency of complications between HTO and supracondylar osteotomies. Risk for superficial wound infection is higher in posttraumatic osteotomies and with continuous corrections. Osteoclasis contains a higher risk for vascular lesion compared to oscillating saw.

Keywords Knee · Osteoarthritis · Osteotomy · Complications · Treatment of complications

Introduction

Osteotomies around the knee are a common treatment for unilateral gonarthrosis or cartilage damage of the medial femoral condyle [1]. Coventry first described lateral closed wedge high tibial osteotomies (HTO) in 1965 [2]. Internal plate fixation for medial open-wedge HTO brought a renaissance to osteotomies [3]. After analysis of the deformity in the frontal plane, distal femoral osteotomies (DFO) are indicated, if the deformity is located at the distal femur,

HTO is performed if the deformity is located at the tibia, double-level osteotomies are necessary in cases with higher correction angle to avoid oblique joint line [4]. Especially because of its assumed lower complication rate, joint replacing surgeries were preferred to osteotomies around the knee joint. But studies about complications in osteotomies around the knee with a large number of cases are rare. To our knowledge, there are only studies documenting complications with a number of less than 500 cases [5]. Other studies report a relatively high overall complication rate of up to 31% after open-wedge HTO [6]. In the study of Schenke et al., complications after osteotomies of the lower limb in a large number of cases are listed [7]. The indications and techniques in this study are very heterogeneous, since diaphyseal corrections tibial and femoral and intertrochanteric osteotomies of the hip joint are included as well as osteotomies around the knee. Especially knee surgeons should be able to compare

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complication rate of osteotomies around the knee with its (partial) joint replacing surgical alternatives. Therefore, we aimed a study to investigate intra- and postoperative complications in a large number of osteotomies with a focus on the knee joint. We hypothesize that osteotomy around the knee joint is a safe surgical procedure with a low complication rate.

Materials and methods

Inclusion and exclusion criteria

Eight hundred and fifty-eight consecutive cases of osteotomies of the lower limb were analyzed retrospectively between 1995 and 2017. For the current study, metaphyseal corrections around the knee joint with a closed growth plate were included. Indication for a correction was unilateral gonarthrosis, patellofemoral maltracking, patella luxation with a torsional deformity or posttraumatic symptomatic deformities. Hence, we performed valgisation or varisation osteotomies, acute or continuous, additive or subtractive, torsional corrections or combined corrections high tibially or supracondylarly; high tibial we also included flexion- or extension osteotomies alone or in combination with corrections in the frontal plane. Exclusion criteria for this study were congenital metabolic disorders (Larsen syndrome, osteogenesis imperfecta, hypophosphatemia, etc.), immunodeficiency (rheumatoid arthritis, lymphoma, etc.), neurological

disease (multiple sclerosis, amyotrophic lateral sclerosis, etc.) and vascular disease (PAD > Level II, angiitis, etc.).

Collection of data

Demographic data collection included age, gender, BMI and smoking habits. Potential risk factors such as obesity (BMI ≥ 30) and nicotine abuse in patients with a complication were compared with patients without complications to detect potential risk factors especially for developing a postoperative infection.

The etiology of deformity (congenital/posttraumatic), mode of correction (acute/continuous), technique of osteotomy (oscillating saw/osteoclasia) and anatomical location of osteotomy (HTO/supracondylar) were documented (Table 1).

Intra- and postoperative complications such as compartment syndrome, deep and superficial infection, vascular lesion and deep-vein thrombosis were analyzed. Complications were collected with a follow-up of 4 weeks postoperatively; data collection started at the beginning of hospitalization. All osteotomies were investigated with the same postoperative protocol, which included investigation of peripheral blood circulation and neurological symptoms each day. In case of abnormalities, further investigations were initiated. Compartment syndrome was diagnosed clinically due to pain level. If compartment syndrome was diagnosed, surgical procedure was initiated immediately. Vascular lesions of the arteria poplitea or its branches were

Table 1 Comparison of etiology (a), mode of correction (b), technique of osteotomy (c), anatomical location (d) and complications: vascular lesion, compartment syndrome, deep-wound infection, superficial infection and deep-vein thrombosis

	Vascular lesion	Compartment	Deep infection	Superficial infection	Deep-vein thrombosis
(a) Etiology					
Congenital $n = 745$	4	4	6	9	3
Posttrauma $n = 113$	1	0	0	5	0
<i>P</i> value	0.651	0.437	0.340	0.012	0.501
(b) Mode of correction					
Acute $n = 852$	5	4	6	13	3
Cont $n = 6$	0	0	0	1	0
<i>P</i> value	0.856	0.872	0.841	0.004	0.891
(c) Technique of osteotomy					
Osteoclasia $n = 15$	1	0	0	1	0
Osz. Saw $n = 843$	4	4	6	13	3
<i>P</i> value	0.002	0.793	0.746	0.121	0.901
(d) Anatomical location					
Supracondylar $n = 338$	2	0	1	3	0
HTO $n = 520$	3	4	5	11	3
<i>P</i> value	0.977	0.107	0.254	0.167	0.163

Additional a statistical analysis with a Chi-squared test for categorical variables was applied (Level of significance $p < 0.05$)

Cont continuous correction, Sc supracondylarly

either detected intraoperatively due to extensive bleeding or they were detected by further (ultrasound) investigations postoperatively, which were performed because of abnormalities in clinical investigation. In cases of extensive wound secretion, indication for surgical revision was set due to clinical conditions of the wound and abnormalities in the blood test (C-reactive protein). Complication was then rated as a deep infection. Extensive swelling without clinical or abnormalities in blood values were treated conservatively as a hematoma. If intravenous antibiotics and cooling dressings had to be applied, complication was defined as a superficial infection.

Eight hundred and fifty-eight osteotomies matched the inclusion criteria (400 female/458 male); mean age was 41 years (standard deviation (SD) 14.1; range 13–76 years), BMI 26 (mean value (MV), SD=4.9; range 15–50). In 192 patients, nicotine abuse was registered, 666 without nicotine abuse.

After long leg analysis, osteotomy was performed either high tibially ($n=520$) as a medial open-wedge or lateral closed wedge (LCW) osteotomy or supracondylarly ($n=338$) as a closed wedge osteotomy [8]. In 843 osteotomies, oscillating saw was used and in 15 cases, a drill hole/chisel osteoclasia was performed. The etiology of deformity was registered as congenital in 745 patients and posttraumatic in 113 patients. Continuous correction was applied in 6 osteotomies, whereas 852 corrections were undertaken acute.

Surgical procedure

The osteotomies were performed by six different surgeons. The surgical procedures included following standards: single-shot antibiotics 30 min before beginning of surgery, arthroscopy prior to osteotomy, no tourniquets during osteotomy, no drain at the osteotomy site, water cooling during osteotomy, osteosynthetic stabilization either by plates, nails or external fixateur, anti-thromboembolic therapy for 4 weeks of partial weight bearing [9]. All osteotomies were done inpatient. After secure wound healing, patients were discharged and next follow-up with X-ray and clinical investigation was performed after 4–6 weeks. Hence, it was ensured that all intra- and postoperative complications were documented during the first 4 weeks.

Statistical analysis

Microsoft Excel (Microsoft, Redmond, Washington, USA) was used for data collection; statistical analysis were performed using SigmaStat software (Systat Software Inc., San Jose, USA). To determine the difference between groups, a Chi-square test for categorical variables was used. Unless stated otherwise, data were expressed as mean \pm SD with

range, as appropriate. P values < 0.05 were considered as statistically significant.

Results

32 complications (3.7%) were recorded in 28 patients (Table 2). 15 major complications (1.7%) occurred such as vascular lesion ($n=5$), compartment syndrome ($n=4$) and deep infection ($n=6$). All major complications needed further surgical treatment. Each major complication is specified separately in Tables 3, 4, and 5.

In five cases of vascular repair, no compartment syndrome, embolism, necrosis or peripheral vascular insufficiency occurred resulting in no further long-term sequels. All five vascular lesions occurred before August 2015.

All six deep infections could be successfully treated with surgical debridement, exchange of internal fixation (plate), vacuum sealing and wound closure by secondary sutures supported by systemic antibiotics.

Compartment syndromes were monitored in lateral closed wedge HTOs exclusively. In two of four cases, two-dimensional correction was performed: valgisation plus torsional correction.

17 minor complications (2.0%) were detected: 3 deep-vein thrombosis and 14 superficial wound infections/hematoma could be treated by conservative procedures. All superficial wound infections/hematoma could be managed conservatively by systemic antibiotics and local anti-septic dressings. Three deep-vein thrombosis were treated by increased anticoagulation and pressure dressing.

No statistically significant difference was seen in frequency of complications in terms of anatomical location (HTO or supracondylar). For superficial wound infection, it was found a statistically significant higher risk in post-traumatic patients ($p=0.012$) and with a continuous correction ($p=0.004$). Risk for a vascular lesion was statistically significant higher ($p=0.002$) with an osteoclasia compared to an osteotomy with oscillating saw.

No statistically significant difference was seen for the other registered complications in etiology of deformity (congenital or posttraumatic), technique of osteotomy

Table 2 Summary of major (*) and minor (**) complications

Complication	Number of cases
vascular lesion*	5
Compartment syndrome*	4
Deep infection*	6
Deep vein thrombosis**	3
Superficial wound infection/hematoma**	14

Table 3 Procedures in patients with vascular lesions

	Surgical procedure	Arterial injury	Surgical treatment	Further complications
Pat 1	Supracondylar torsional correction	A. poplitea (P1)	Vein interposition	ASA for 1 year
Pat 2	Supracondylar torsional correction	A. poplitea (P1)	Primary suture	ASA for 6 weeks
Pat 3	MOW HTO	A. poplitea (P2) with “false aneurysm”	8 days postoperatively secondary suture	ASA for 3 months
Pat 4	MOW HTO	A. poplitea (P2) with “false aneurysm”	15 days postoperatively secondary suture	9 months NOAK, 6 months ASA
Pat 5	MOW HTO	A. tib. ant	Primary suture	ASA for 3 months

NOAK new oral anticoagulants, ASA acetylsalicylic acid

Table 4 All four patients are listed, who suffered compartment syndrome

	Surgical procedure	Additional procedures	Fasciotomy (compartment)	Further complications
Pat 1	9° valgisation (LCW)	None	Day 1	Superficial wound infection → antibiotics, dorsal ankle extension 3/5
Pat 2	9° valgisation (LCW), 10° internal rotation	Fibula osteotomy, neurolysis, fasciotomy proximally	Day 4	Deep infection, dorsal ankle extension 1/5
Pat 3	8° valgisation (LCW), 8° internal rotation	Fibula osteotomy	Day 1	None
Pat 4	13° valgisation (LCW)	Fibula osteotomy	Day 2	Dorsal ankle extension 3/5

Table 5 All six patients with deep infections are listed

	Surgical procedure	Microbiology	Surgical procedures	Further complications
Pat 1	LCW HTO	Staph. epidermidis	8 revision surgeries (due to compartment syndrome), VAC, change of internal fixation	dorsal extension 3/5 (ankle)
Pat 2	MOW HTO	Staph. aureus	4 revision surgeries with debridement, conversion to external fixation	None
Pat 3	Supracondylar varisation	Bacillus cereus	One revision surgery with surgical debridement	None
Pat 4	MOW HTO	Staph. epidermidis	One revision surgery with debridement	None
Pat 5	MOW HTO	Propionibacterium acnes, Corynebacterium species	2 revision surgeries, exchange of internal fixation (plate)	None
Pat 6	MOW HTO	Staph. haemolyticus, Staph. epidermidis	3 revision surgeries with VAC, exchange of internal fixation (plate)	None

Staph staphylococcus, VAC vacuum occlusion therapy

(osteoclasia or oscillating saw) and mode of correction (acute or continuous).

20 patients developed a wound healing problem, 4 of them were cigarette-smoker, 5 of them obese (BMI ≥ 30) and 2 of them both. Statistical analysis revealed no significant higher risk for wound infections in patients with nicotine abuse or obesity or both combined (Table 6).

No other severe complication such as pulmonary embolism, and myocardial infarction occurred during inpatient stay or 4 weeks postoperatively.

Table 6 Patients with wound infections (deep or superficial) and potential risk factors obesity and nicotine abuse

	With wound infection	Without wound infection	P value
Total	20	828	
Nicotine	4	192	0.739
BMI ≥ 30	5	299	0.306
BMI > 30 + nicotine	2	52	0.502

Discussion

Vascular lesion

Vascular lesions are limb-threatening incidents. The rate for vascular lesions in total knee replacement surgery differs between 0.003 and 0.23% [10–12]. Compared to that the risk for a vascular lesion in our cohort was higher (0.58%). One lesion occurred with drill hole/chisel technique in a distal femoral osteotomy. All four remaining lesions occurred with oscillating saw, one in a distal femoral osteotomy and three in open-wedge HTO. Three of them were registered in a short period of time in 2011, where AO engines were replaced by “power engines”. After fifth vascular lesion, operative technique was slightly changed: curved raspatorium, so called “power engines” and saw blades (used for total hip and knee replacement) were replaced by a blunt retractor, a precise saw and a 0.86 mm saw blade (Fig. 1). After implementation of these changes, no further vascular lesion was registered in 168 consecutive osteotomies (before 5 vascular lesions in 676 osteotomies were registered). Statistical higher risk for vascular lesion with drill hole/chisel osteoclasia compared to oscillating saw has to be modified due to low number of vascular lesions overall (one versus four).

Compartment syndrome

Compartment syndrome exclusively occurred in LCW tibial osteotomies. Table 4 shows surgical procedures, time of fasciotomy, when compartment syndrome was diagnosed and further persisting complications. It is well known, that compartment syndrome has to be treated by surgical complete fasciotomy as soon as possible to avoid persisting damage especially to the tibialis anterior muscle. This is confirmed by our findings: the later fasciotomy was performed the worse function of dorsal ankle extension was observed. In

three of four cases, no fasciotomy and peroneal neurolysis was performed in primary surgery together with osteotomy.

The combination of a valgisation and a torsional correction simultaneously (Pat. 2 and 3) and LCW osteotomy with a higher correction angle (Pat. 1 with 9°, Pat. 4 with 13°) obviously is predisposed for a higher risk of compartment syndrome. Therefore, we recommend a fasciotomy in torsional corrections of more than 10° or in cases with a combined valgisation and torsional correction, because these cases are exposed to a higher risk for developing a compartment syndrome. If there is any doubt concerning compartment syndrome in the postoperative treatment, early surgical revision improves general outcome of the patient.

Deep infection

Deep infections are serious complications with a major influence on patients’ long-term outcome. All six cases were treated with surgical revision (Table 5), whereas retrospectively in two patients (Pat 3 and 4 in Table 5) microbiological samples may have been contaminated. In the other four patients, deep infection was treated by at least two (up to eight) revision surgeries including exchange of internal fixation (plate). Obviously, postoperative treatment had to be adjusted and inpatient stay was extended. But in all cases, the infection was successfully eradicated and no osteomyelitis remained. No loss of correction was obtained by changing internal fixation and postoperative treatment. Risk for deep infection in our cohort (0.70%) seems to be relatively low compared to other studies; in a systematic review rate for deep infection after HTO was stated between 0.5 and 4.7% [13]. This must be kept in mind when planning conversion to TKA, since infection rate in these cases is higher than in primary TKA [14]. In a recent study, Kawata et al. [15] reveals the use of artificial bone graft as a significant risk factor for an infection after HTO, whereas in our cases of deep infection, no artificial bone graft was used.

Fig. 1 Blunt retractor, precise saw and a 0.6 mm saw blade as used in our institution since 2015



Superficial infections

14 superficial wound infections (1.6%) were managed with conservative treatment. In a systematic review, the risk for superficial wound infection after HTO was between 1 and 9%, which matches our findings. Higher risk for wound infections was found in posttraumatic patients (5 out of 113; 4.4%) and in patients with a continuous correction (pin track infection, 1 out of 6; 17%), which matches the findings in the common literature. Posttraumatic situations in general are known for a higher risk of wound and deep infections [11, 16].

Obesity and nicotine abuse

Obesity and nicotine abuse are assumed risk factors for developing infections postoperatively in surgeries around the knee joint. Our findings do not confirm this thesis, since neither patients with obesity nor nicotine abuse alone nor both combined had a higher risk for wound infection. This confirms the results of Floerkemeier et al. who found no correlation between smoking habits/obesity and a higher complication rate in patients after open-wedge HTO [17]. Of course, there is a bias in this retrospective analysis of risk factors in patient selection and choice of technique of osteotomy prior to surgery. Hence, special care should be taken on patient selection in terms of technique of osteotomy and other potential risk factors (diabetes mellitus, medication etc.).

Limitations and further considerations

The rate for symptomatic deep-vein thrombosis (0.3%) is relatively low compared with total knee arthroplasty (TKA) implantation (rate between 1.9 and 6.6%), although patients have partial weight bearing after osteotomies compared to full weight bearing after regular TKA/unicondylar knee arthroplasty (UKA) [18, 19]. Moreover, only symptomatic deep-vein thrombosis were registered, no ultrasound or other investigation were performed to determine a non-symptomatic deep-vein thrombosis. It may have an influence that no tourniquets in osteotomies are used, although Motycka et al. found no difference in incidence of deep-vein thrombosis with or without use of tourniquets in HTO [20].

In the process of planning an osteotomy around the knee in some cases, both tibial and femoral corrections are possible. Our findings show that the risk for a major complication for both techniques is equal, which matches the findings of Delva et al. [21].

In our study, only BMI and nicotine abuse were registered as comorbidity, whereas other potential risk factors

were not monitored. Cotter et al. [22] presented patients with age > 45, diabetes mellitus, chronic obstructive pulmonary disease as potential risk factors for an adverse event during osteotomies around the knee.

Another limitation of our study is that intraoperative hinge fractures were not registered. Han et al. [23] described undisplaced (12.0%) and displaced (2.4%) lateral hinge fractures in HTO as minor complications. Song et al. found a lateral hinge fracture of more than 20% in his cohort, but similar radiographical and clinical results 1 year postoperative compared to patients without hinge fracture, although time to bony union was longer [24].

The purpose of the current study was to register perioperative complications in osteotomies around the knee joint. We focused on the surgical procedure itself and its security in terms of complication rate. We did not investigate the success of the surgery, which could be monitored by pain level or clinical scores. After osteotomies of the knee, there are conditions, which could lead to revision surgery, such as over-/undercorrection or non-union. This can be usually traced back to the operative technique and was not analyzed in this study.

The authors do not claim complete registration of all complications in the 4-week postoperative period. Especially the number of undiagnosed deep-vein thrombosis may be higher than recognized.

Although we focused on osteotomies around the knee joint with a high number of cases, the range of indications and surgical techniques still is wide. Since complications are rare in osteotomies around the knee, inclusion criteria for this study were extended from correction in the frontal plane to torsional corrections, where operative technique is similar. Further studies have to be obtained with a large number of cases and with same indication and operative technique to reach comparability to its surgical alternatives for example in unicompartmental gonarthrosis.

Conclusion

Osteotomy around the knee is a safe procedure and major complications are rare (1.7%). Obesity and nicotine abuse are no risk factors for a wound infection. Femoral and tibial osteotomies are equal in terms of frequency of complications. In posttraumatic deformities and continuous corrections, risk for superficial wound infection is higher. Osteotomy with oscillating saw is safer than osteoclasis in terms of vascular lesion and we recommend special saw blades and retractors to minimize the risk for a vascular lesion.

Compliance with ethical standards

Ethical approval All the procedures performed in this study were in accordance with the ethical standards of the institutional research committee (ethical committee Friedrich-Alexander-University Erlangen, reference number 38_15 Bc).

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Medial open wedge vs. lateral closed wedge high tibial osteotomy - Indications based on the findings of patellar height, leg length, torsional correction and clinical outcome in one hundred cases

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Abstract

Introduction Medial open wedge (MOW) and lateral closed wedge (LCW) osteotomies are established methods to treat medial gonarthrosis. Advantages and differences in the outcome of the two techniques have been discussed controversially and there is still no precise recommendation for either technique. We now aimed to assess the effect of each technique on tibial slope (TS), patella height (PH) and leg length discrepancy.

Method In a study of 50 consecutive cases of MOW and 50 of LCW osteotomies were registered. The decision for either technique was made pre-operatively according to an algorithm. Demographic data, operation procedures (time of operation, correction angle, torsional correction) and measurement of patellar height, tibial slope, leg length discrepancy, clinical outcome after one year and bone and wound healing were obtained. Pre- and post-operative values were compared between the two groups.

Results In absence of randomization demographic data demonstrate comparability of the two groups. No difference in bone and wound healing, time of operation and clinical outcome was seen. In the MOW group PH decreased significantly, no relevant alteration of PH was detected in the LCW group. In the latter group a statistically significant decrease of TS compared to a slightly decrease in the MOW group was recorded post-operatively. A significant leg lengthening with the MOW and shortening of the leg with the LCW method can be achieved.

Discussion With respect to similar results in operating procedures, bone and wound healing and clinical outcome decision making factors for either technique should be leg length discrepancy and torsional deformities. Changes of PH and TS have to be known and may influence the technique of osteotomy in cases of patella infera / alta or borderline PH.

Conclusion An algorithm for valgus high tibial osteotomies based on TS, PH and leg length discrepancy may be proposed.

Keywords Gonarthrosis · Osteotomy · Varus deformity · Surgical technique

Introduction

Osteotomies around the knee joint for the treatment of gonarthrosis experience a renaissance within the last decade. By the development of a rigid plate fixateur [1] the problem of bone healing after opening osteotomies seemed to be solved. Consequently, medial open wedge (MOW) osteotomy became the most common surgical joint preserving procedure in patients with a high tibial deformity and a medial gonarthrosis. The technically easier operative approach medially avoids fibular nerve lesion and fibula osteotomy. But, the lateral closed technique (LCW) still owns its relevance in the treatment of medial gonarthrosis. Different studies investigated the advantages and disadvantages of these two different techniques;

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patella height and its change through the osteotomy have been subject to a few previous studies. [2] Does a high tibial valgisation osteotomy really produce a patella baja or does the change of patellar height (PH) and tibial slope (TS) create a problem post-operatively? Controversary results have been published concerning complications after HTO such as delayed or non-union, (deep) infections or nerve lesion. [3] El-Azab claims further investigation on clinical outcome following HTO, especially associated with PH and TS changes. [4]

We therefore now aimed to assess the effect of each technique on TS, PH and leg length discrepancy; furthermore a decision making support / algorithm for either LCW or MOW technique in the treatment of medial gonarthrosis should be established.

Material and methods

Preoperative Planning

Between 2006 and 2014 we investigated 100 consecutive cases of femoro-tibial varus with high tibial deformities. All included patients were treated based on the assessment of patients not included in the current study sample according to clinical and radiographical findings. Clinical investigation consisted of measuring range of motion of the hip and knee joint and torsion of lower leg for detecting torsional deformities. In patients with a torsional deformity a computer tomograph (CT) scan was performed according the protocol of Waidelich and torsional correction was planned. [5] Leg length discrepancy was measured by the senior author (WS) clinically with the patient in supine position; examiner measures leg length discrepancy between the two heels in accordance to method of Strecker et al.. [6] PH was measured on a lateral view radiograph of the knee and Blackburne-Peel (BPI) [7] and Caton-Deschamps-Index (CDI) [8] were calculated (figure 1). Based on these findings patients were then treated according to our algorithm (figure 2).

Demographic data such as age at operation, body mass index (BMI) and cigarette smoking were registered.

Surgical technique

In this monocentric study all operations were performed or assisted by the same three experienced orthopaedic surgeons (JD, JH, WS) after arthroscopical evaluation of the cartilage and if necessary, arthroscopical treatment.

MOW was performed according to the protocoll of Galla and Lobenhoffer [9] using a rigid internal plate-fixateur (Tomofix®, Synthes, West Chester, USA) (figure 3), LCW according to the protocoll of Strecker [10]. Both cited surgical procedures use a biplanar osteotomy with the vertical osteotomy usually above the insertion of the patellar ligament,



Fig. 1 Measurement of patella height. Anterior-posterior (left) and lateral (right) radiography of the knee post-operatively after LCW osteotomy. BPI is defined by the quotient of lines 1 (distance between the distal pole of the patella and the expanded tibial joint line) and 3 (length of the articular surface of the patella). CDI is calculated by the quotient of lines 2 (distance between the distal pole of the patella and the frontal upper tibia limit) and 3. (LCW, lateral closed wedge; BPI, Blackburne-Peel index; CDI, Caton-Deschamps index)

which potentially could lead to a change in patella height. The MOW technique does not provide intentional torsional corrections. In LCW without torsional correction medial hinge should not be osteotomied and lateral gap should be slowly closed completely by fixating a 5-whole locking-compression-plate (Synthes, West Chester, USA) laterally (figure 1). Surgical data such as correction angle, torsional correction, time of operation and osteotomy of the fibula in LCW was recorded. The listed operating time contains all arthroscopical procedures.

Post-operative rehabilitation

Post-operatively, all patients were treated after a standardized protocoll with partial weight bearing with 20 kilogram (kg) for four weeks; then radiographs of the knee were performed and load was increased with 20 kg per week until full weight bearing was achieved. All patients received physiotherapy including continuous passive motion with an unrestricted range of motion adapted to pain level and gait training starting on first post-operative day. Wound healing was assessed clinically and it was recorded as wound-healing disturbance if reoperation due to soft tissue problems had to be performed.

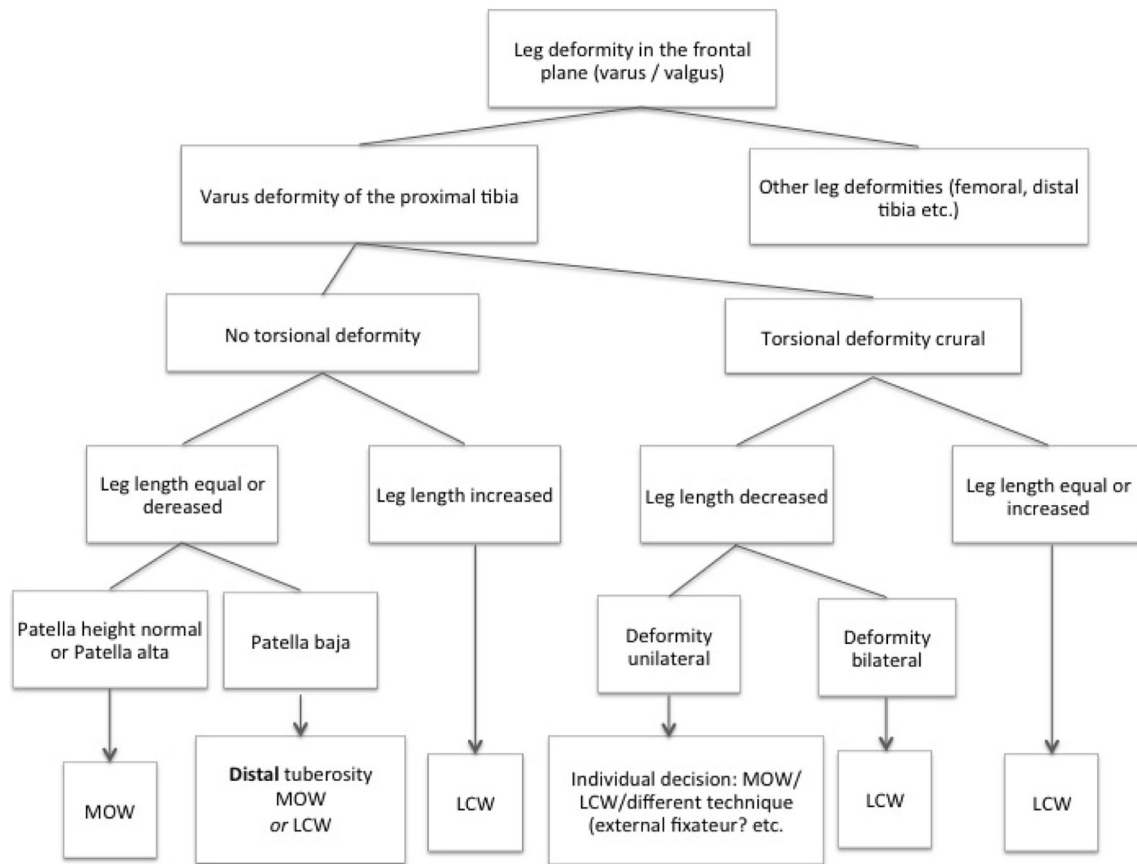


Fig. 2 An algorithm for tibial valgus deformity was developed that guides the surgeon to the right technique of high tibial osteotomy with regard to torsional deformity, patella height, and leg length discrepancy

Post-operative assessment

PH and TS was measured as described by Paley [11] on radiographs pre-operatively and four weeks after surgery (figures 1 and 3). For evaluation of patellar height BPI and CDI were measured pre/post-operatively and changes were calculated.

Bone healing was assessed clinically and radiographically after four months; if bone healing was not completed after four months, second follow up radiographs were evaluated after eight months. Patients were classified as complete bone healing (after 4 months), delayed union or non-union in cases of incomplete bony healing after eight months. Three orthopaedic surgeons in consent performed the assessment.

For clinical evaluation questionnaires were handed out pre-operatively and one year post-operatively. Severity of pain was registered by a numeric rating scale (NRS). Japanese Knee score (JKS) and Tegner Lysholm Score (TLS) was recorded and compared within the two groups pre- and post-operatively.

Statistical analyses

Microsoft Excel was used for data collection; statistical analyses were performed using SigmaStat software (Systat

Software Inc., San Jose, USA). Data were expressed as mean \pm standard deviation and p -values <0.05 were considered statistically significant. A Rank-sum test or t -test was used to determine the difference between groups.

The study was approved by the institutional review board and all patients provided written informed consent.

Results

Demographic Data and operating procedures

No statistically significant difference was detected in terms of patients' age at operation, BMI, gender distribution and the percentage of cigarette smokers (table 1).

Due to a large correction angle ($>10^\circ$) in 14 patients with a LCW osteotomy a fibula osteotomy had to be performed. Torsional correction was performed in ten cases of LCW simultaneously to the correction in the frontal plane. [12]

Operation time in LCW was slightly longer, but no statistical difference could be detected (table 1). In both groups, arthroscopy was performed prior to the osteotomy and, if necessary, arthroscopical procedures were performed. The most common procedures were: partial meniscal resection,



Fig. 3 Measurement of tibial slope/proximal posterior tibial angle (PPTA). It is measured on a post-operative anterior-posterior (left) and lateral radiography of the knee after MOW osteotomy. PPTA is defined as the angle between the tibial joint line (asterisk) and the line drawn between a point marking the ventral 4/5 of the tibial plateau and a point bisecting the diameter of the tibia (pound sign) diaphyseally. Some authors measure tibial slope angle, where PPTA has to be subtracted from 90° resulting in an angle of $+2^\circ$ in the current patient. Negative values indicate an anterior slope (PPTA $> 90^\circ$)

chondral abrasio, meniscal repair or matrix associated autologous chondral transplantation. Correction angle was slightly larger in the MOW group, but the difference was not significant (table 1).

Bone and wound healing

In terms of bone healing more delayed unions were found in the MOW group, however this finding was not supported by statistical significance. The number of non-unions was equal

within both groups. Therefore, complete bone healing was detected after 4 months in 43 (86%) patients after LCW and in 38 (76%) patients after MOW osteotomy, which reveals no statistically significant difference ($p=0.4$).

No significant difference was seen in regards to wound healing and no deep infection occurred (table 2).

Leg length discrepancy, patella height and tibial slope

Leg length decreased by 0.1 cm after LCW osteotomies and increased by 0.5 cm after MOW osteotomies. This difference is seen statistically different resulting in a relevant manipulation of leg length with the different techniques.

Post-operative BPI decreased by -0.1 as compared to pre-operative values within the MOW group, whereas no changes in BPI were found following LCW osteotomies. Accordingly, CDI showed a difference of -0.1 following MOW and no difference (0.0) following LCW osteotomies (table 2). This implies a significant decrease of PH after MOW as compared to LCW and no significant change of PH following LCW osteotomies. Pre-operative tibial slope (TS) did not differ between both groups; while TS decreased in both groups post-operatively, this decrease was significantly higher in the LCW group as compared to the MOW group (table 2).

In figure 4 A-C box plots depict the differences graphically.

Clinical outcome

Questionnaires were complete in 82 cases, three patients (LCW group) died within the follow-up period independently from the surgery resulting in 82 out of 97 (84,5%) completed questionnaires. 41 out of 50 (82%) cases of the MOW and 41 out of 47 (87,2%) of the LCW group were complete.

Neither pre- nor post-operatively, a significant difference was seen between the LCW and MOW group when clinical scores and painlevel were recorded. Improvement of all scores

Table 1 Demographic and operating data within both groups are listed (BMI, body mass index; LCW, lateral closed wedge; MOW, medial open wedge)

		LCW	MOW	<i>p</i> value
Demographic data	Age in years*	45 (15–62; 11.4)	45 (20–68; 11.5)	0.77
	Gender	19 female (38%)	16 female (32%)	0.53
	BMI*	27 (19–43; 5.2)	28 (21–37; 4.0)	0.29
Operating data	Number of cigarette smokers	15 (30%)	8 (16%)	0.09
	Correction angle in degree*	8.0 (3.0–15; 3.1)	8.3 (4.0–18; 3.2)	0.77
	Operating time in minutes*	134 (60–338; 50.9)	119 (47–231; 44.0)	0.13

*Mean value (range; standard deviation)

Table 2 Post-operative results: wound and bone healing, change of leg length discrepancy, patellar height, and posterior proximal tibial angle (MV, mean value; SD, standard deviation; PPTA, posterior proximal tibial angle; BPI, Blackburne-Peel index; CDI, Caton-Deschamps index)

		LCW	MOW	p value
Wound healing	Number of wound healing disturbances	2 (4%)	3 (6%)	0.65
Bone healing	Number of delayed unions	5 (10%)	10 (20%)	0.16
	Number of non-unions	2 (4%)	2 (4%)	1.0
Leg length	Change of leg length MV (range; SD)	- 0.1 cm (- 0.5 to + 1.0; 0.3)	+ 0.5 cm (- 0.4 to + 1.2; 0.4)	0.016*
Patellar height	Change of BPI	0.0	- 0.1	0.001*
	Change of CDI	0.0	- 0.1	< 0.001*
	MV (range; SD)	(- 0.2 to + 0.3; 0.1)	(- 0.4 to + 0.2; 0.1)	
Tibial slope	Change of PPTA (MV)	+ 3.9°	+ 1.5°	0.001*

*Statistically significant difference

after surgical treatment was detected to be statistically significant, respectively. Accordingly, pain level decreased significantly within both groups (table 3).

Discussion

Influence on patella height

The current study presents a comparison of the two most common techniques of HTO - LCW and MOW - and confirms that the two techniques are absolutely equal in terms of operating time, wound healing, bone healing and clinical outcome. This finding goes along with the findings of Smith. [3] The most important difference between the two techniques is the change of leg length, PH and TS.

We selected BPI and CDI as measurement tools for the detection of changes of PH, as these measurement techniques provide the ability to identify changes between the patella and the tibial joint line. The relation between BPI/CDI and TS has to be accepted and kept in mind, when overall conclusions concerning PH and TS are drawn.

Although the alteration of PH by valgus HTO has been subject of several previous publications, its definite effect is still discussed controversially. [4, 13, 14] A statistically significant lower PH following MOW compared to LCW osteotomies was described by Smith et. al. [3] In contrast to the Insall-Salvati Index (ISI), which showed no significant difference, measurements of BPI and CDI revealed a significant decrease of the PH.

In a radiological comparative study on 100 osteotomies El-Azab et. al. found a decrease of PH after MOW measured with BPI, CDI and ISI. [4] The change of PH achieved by surgery

turned out to be stable over time until hardware removal. A distalisation of the patella after MOW osteotomy is confirmed by Portner et. al. with a different method of measurement: The authors used the plateau-patella angle as a reliable measurement tool. [13, 15]

The current measurements on 50 consecutive osteotomies acknowledge the lowering of the patella after MOW osteotomy. This change was predicted in a biomechanical cadaver study, where a significant decrease after MOW and increase after LCW osteotomies measured on a continuous 3D monitoring of the patella was observed. [16] This biomechanical measurement of a proximalisation of the patella following LCW osteotomies is confirmed in different clinical publications [3, 4, 13], whereas the results of the current study differ from these findings. In their previously mentioned study, El-Azab et. al. showed that PH increased in their group of 50 LCW osteotomies. [4] Comparable to the MOW method, the PH changes persisted until hardware removal. This significant ascent of the patella following LCW procedures is acknowledged by Portner's measurements of the plateau-patella angle. [15]

In 24 LCW osteotomies Brouwer et. al. calculated BPI and ISI and found a slightly increase of PH and a significant difference to the decrease of PH after 26 MOW osteotomies. [17] The critical use of BPI for PH changes after HTO due to its relation to tibial inclination changes has already been discussed. [17]

Tigani et. al. measured PH changes in 47 LCW osteotomies by CDI and found a tendency for elevation of the patella especially when correction angle was less than ten degrees; overall the increase of CDI was not statistically significant. [14] The two latter cited publications tend to the findings of the current investigation, where no significant change of PH was observed.

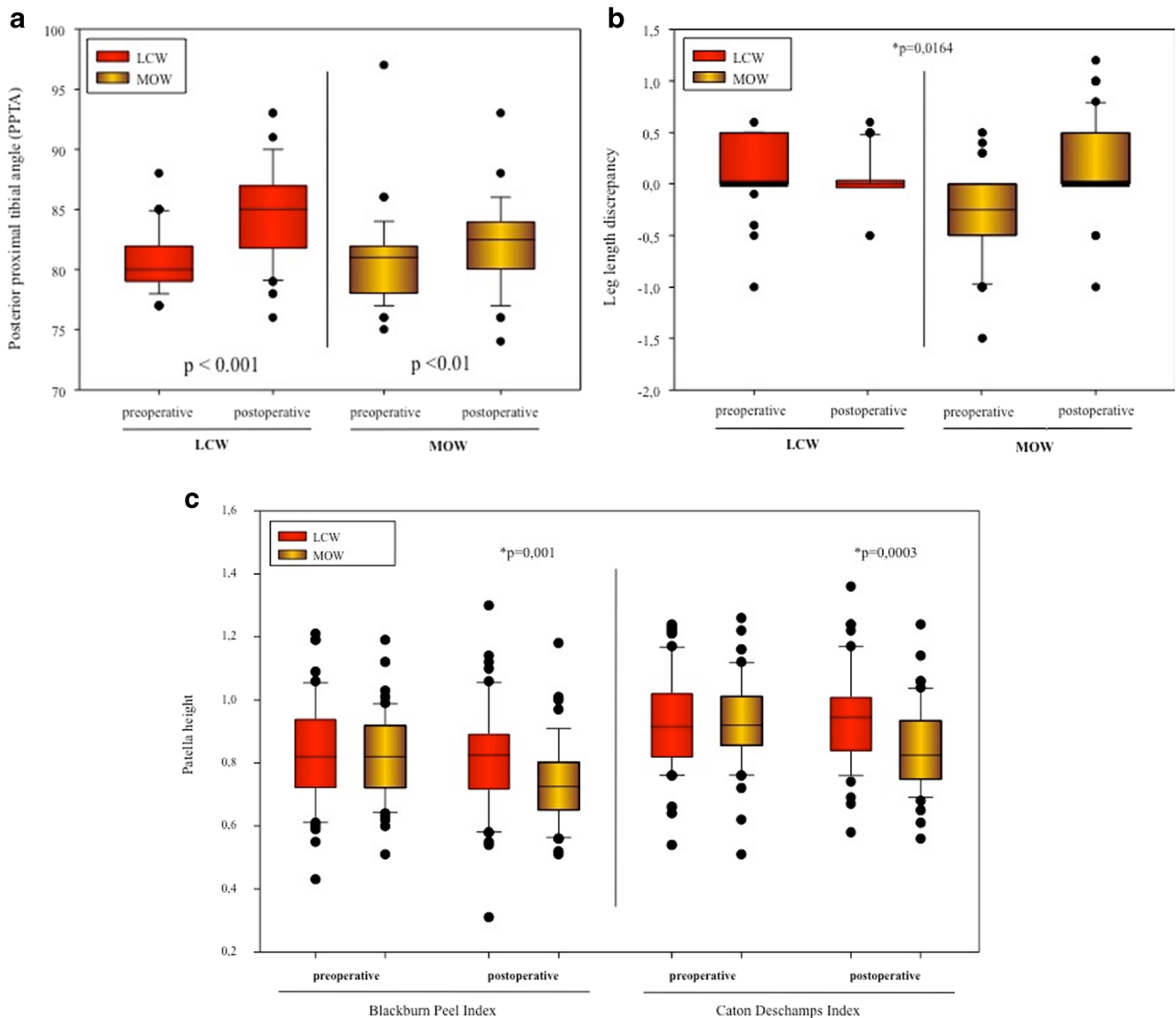


Fig. 4 a–c Boxplots in a depict change of PPTA, in b leg length discrepancy, and in c patella height—measured by CDI and BPI—is shown. *p* values indicate statistical significance

Table 3 Clinical scores (maximal score is 100 each) and pain level (between no pain, 0, and maximum pain, 10) pre- and postoperatively at 1-year follow-up are compared between the LCW and MOW groups (LCW, lateral closed wedge; MOW, medial open wedge; JKS, Japanese

knee score; TLS, Tegner-Lysholm score; NRS, numeric rating scale; MV, mean value; SD, standard deviation; *preop*, pre-operative; *postop*, post-operative)

		LCW (MV, range; SD)			MOW (MV, range; SD)		
		preop	postop	<i>p</i> value	preop	postop	<i>p</i> value
Clinical scores	JKS	65 (37–91; 11)	91 (45–100; 12)	< 0.001*	66 (42–98; 13)	92 (55–100; 11)	< 0.001*
	TLS	45 (10–83; 20)	84 (33–100; 16)	< 0.001*	51 (17–98; 19)	85 (25–100; 19)	< 0.001*
Pain level	NRS	7.6 (3–10; 1.7)	3.1 (1–7; 1.5)	< 0.001*	7.2 (3–10; 2.0)	3.3 (0–10; 2.1)	< 0.001*

*Statistically significant difference

Biomechanically, an increased patellofemoral pressure is caused by MOW osteotomy in the classical technique (proximal the tuberosity) due to a descent of the patella compared to the LCW or distal tuberosity MOW osteotomies. This implicates the recommendation to use LCW or distal tuberosity MOW techniques in cases of (borderline) patella infera or mild symptomatic patellofemoral osteoarthritis.

Tibial slope in relation to patella height

The relation between PH and TS has to be kept in mind. Changes of TS itself after HTO has widely been discussed in the past. In a retrospective study in 67 patients with LCW osteotomy a statistically significant decrease of TS was demonstrated. [18] Reduction of TS by LCW technique corresponds to the findings by different other authors. [4, 19] However, an increase of TS after MOW osteotomies was described in a review analysis by Smith et. al. [3] The authors summarized four different publications, where TS presented with a significant increase after MOW and decrease after LCW osteotomies. [17, 19] In other studies increase of TS with MOW technique appeared not to be significant. [13]

Taking out one study with a significant increase of TS following MOW osteotomy, El-Azab's technique as well as their inclusion criteria deviate from those of the current study: The authors excluded patients, where TS was changed intentionally. [4] In the current study, however, those patients were included. The goal of surgical technique in the current cohort was not to leave an extension deficiency, which in some cases can only be obtained by an intentional decrease of TS. Still, anterior TS (PPTA > 90°) has to be avoided. This difference in the surgical technique might explain the slightly decrease of TS in the MOW group, whereas currently observed TS changes with LCW technique correspond to the cited changes. [20] Range of motion was controlled and documented intraoperatively after correction was completed and full extension (0 degrees) was achieved in all cases.

There is an uncontroversial dependency of BPI and CDI on TS. [2] Decrease of TS results in a change of PH. Measurement of CDI seems to be less affected than BPI. TS and PH therefore can't be evaluated separately in this setting and the exact correlation still remains unclear. According to geometrical considerations the CDI seems to be the most valuable and most unaffected PH measuring tool when it comes to TS following HTO. [21]

According to the normal range of PH two patella infera and six patella alta occurred in the current study population pre-operatively. Post-operatively, three patella alta and five patella infera were detected. Consequently, patella abnormalities occurred in less than 10% of the patients. The technique of the osteotomy influences latter group and borderline values of PH. In any case, disturbances of PH have to be recognized when planning a HTO and it should be recognized that PH and

TS might have been altered through HTO when planning a total knee arthroplasty after HTO. [22]

Limitations of the study

Pre-operative planning was performed on long leg radiographs (double-limb stance). [23] Post-operatively, the achieved hip-knee-ankle axis was not measured again to avoid further radiation exposure. Consequently, the exact correction that was achieved and its possible deviation from the pre-operative planning were not determined. Although hip-knee-ankle axis was evaluated clinically post-operatively, the degree of precision of either osteotomy technique cannot be demonstrated in our study.

Clinical outcome and improvement of pain levels after one year was similar with the two described techniques. This is acknowledged by short- and mid-term results. [24] Long-term outcome has to be obtained in the current cohort.

Mean operation time in both groups was longer than in MOW/LCW procedures due to arthroscopical procedures. The tendency to a longer operation time may depict the technically more difficult method of LCW technique, which included torsional osteotomies (in ten cases) and additional osteotomy of the fibula (in 14 cases).

Investigation of leg length with the presented method seems to be dependent on the examiner. However, all leg length examinations were performed by the senior author (WS), who is a board certificated and very well experienced surgeon for leg deformities. Secondly, even though very accurate values of leg length can not be measured, tendencies to leg length discrepancy can definitely be detected by the described method of examination. Thirdly, in many cases torsional deformities were suspected clinically and had to be investigated radiographically by torsional CT-scans. This investigation includes measurement of femoral and tibial length. Consequently, an exact value for leg length existed and a correlation to clinical measurement was possible. Strecker et al. has shown a strong correlation between the clinical examination and torsional CT-scan. Magnussen et. al. postulated, that changes in leg length after HTO (LCW versus MOW) are less than mathematical models predicted. [25] However, in their measurements on long leg radiographs pre- and one year post-operatively the authors found a significant change of leg length by the different techniques of osteotomy according to the current findings. Thus, leg length discrepancy should be considered before decision is made to either technique.

If torsional correction is necessary, LCW is the method of choice. Most common disease in this constellation is a (mild) varus deformity associated with an increased external tibial torsion (and sometimes increased internal femoral torsion) leading to patella maltracking (inwardly pointing knee).

Another limitation is the absence of a randomization; of course there is a bias of patient selection for the two groups.

Nevertheless, by demonstrating demographic data and correction angle the comparability of the two groups is ensured.

Conclusion

There is no difference in complications, bone healing, functional outcome or pain level between LCW and MOW technique. Consequently, leg length discrepancy and torsional correction should be the decision making factors for either method. PH has to be considered in pre-operative planing. The correlation of PH and TS and its decrease by either technique has to be kept in mind.

In summary, positive clinical and radiographical results of the patients treated according to our algorithm (figure 2) confirm our therapeutical approach. Based on the current findings our algorithm can be established for the different techniques of valgus HTO. Before final decision is made to either technique demographic conditions such as nicotine abuse, BMI, special medication etc. are subject to careful consideration on the way to an individual customized solution for each patient and problem.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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Is a synthetic augmentation in medial open wedge high tibial osteotomies superior to no augmentation in terms of bone-healing?



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ABSTRACT

Introduction: Medial open-wedge high tibial osteotomy (MOWHTO) is an established method to treat unicompartmental osteoarthritis of the knee joint. However, augmentation of the created tibial gap after osteotomy is controversially discussed.

Methods: We performed a prospective investigation of 49 consecutive cases of MOWHTO at our department. Patients were divided into two groups: group A consisted of 19 patients while group B consisted of 30 patients. In group A, the augmentation of the opening gap after osteotomy was filled with a synthetic bone graft, whereas group B received no augmentation. As an indicator for bone healing we investigated the non-union rate in our study population and compared the non-union-rate between the two groups.

Results: The non-union rate was 28% in group A (five of 19 patients had to undergo revision) which received synthetic augmentation, while it was 3.3% in group B (one of 30 patients had to undergo revision) which received no augmentation. The difference between the groups was statistically significant (p -value 0.027).

Conclusions: With regard to bone healing after MOWHTO, synthetic augmentation was not superior to no augmentation in terms of non-union rates after surgery. In fact, we registered a significantly higher rate of non-union after augmentation with synthetic bone graft.

Level of evidence: III

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1. Introduction

In the mid-nineteenth century Langenbeck [1] first described the operative technique of leg correction. In the late 1950s and 1960s Jackson [2,3] reported on osteotomy around the knee for the treatment of osteoarthritis of the knee joint. In the following decades the technique of high tibial osteotomy became an established method to treat osteoarthritis of the medial compartment of the knee in patients with a varus deformity of the leg as confirmed by Coventry's investigations [4,5]. Valgisation helps to prevent or delay unicompartmental or total replacement of the knee in patients with well preserved cartilage in the lateral compartment of the joint. A number of techniques have been developed and modified in the last few decades. The lateral closed wedge technique is associated with different disadvantages. Some authors still perform fibula osteotomy, lateral muscle detachment or dissection of the peroneal nerve. Consequently this technique has been replaced more frequently by the procedure of medial open wedge high tibial osteotomy (MOWHTO), which is devoid of these disadvantages [6]. However, MOWHTO is associated with loss of correction and delayed-union or non-union of the open wedge gap after osteotomy [7]. Although surgical techniques and especially the type of

bone fixation — such as locking plates — have been improved a lot [8], augmentation of the gap is still controversially discussed and not yet clear. A review of the published literature concerning high tibial osteotomy [9] shows that one of the issues to be addressed in the future is graft selection.

Filling materials after MOWHTO have been compared in some studies [10]. Autologous bone grafting remains the gold standard for bridging of bone gaps because of the osteoinductive and osteogenic properties of the autologous bone graft [6]. However, the main problem of this method is harvesting of the autograft, which is associated with donor site morbidity and prolonged operating time and has led to a search for alternative techniques. Some authors revealed good short-term results in terms of bone healing using an allogenic bone graft [11–13]. But on the other hand allograft has poorer osteoinductive properties and there is still the risk of transmission of disease.

As another possibility in recent years the augmentation with a synthetic material has become more popular and there are some studies existing investigating the value of a synthetic bone graft. Koshino et al. [14] registered satisfactory results in his clinical study. The authors used hydroxyapatite (HA) wedges as filling material in 21 knees and observed no case of recurrence of varus deformity or collapse of the porous HA wedges.

To our knowledge no prospective randomized study has yet been performed to compare the use of filling materials with no filling of the gap. We prospectively analyzed bone healing after MOWHTO in

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patients without filling material compared to those treated with synthetic bone augmentation.

2. Materials and methods

2.1. Inclusion criteria

Symptomatic patients with a varus malalignment causing a mechanical overload on the medial compartment of the knee joint were included in the study. After analysis and planning of deformity correction only patients with a MOWHTO were included in the investigation, whereas those with femoral correction or lateral closed wedge high tibial osteotomies were excluded.

Fifty-seven consecutive cases of MOWHTO, performed in 49 patients, by the two senior authors between July 2004 and March 2011, were included in the study. For statistical analysis, patients who were operated on both knees, the first knee was chosen and the second knee excluded, due to possible dependency in the patient.

The population was divided into two groups: group A consisted of 19 knees and group B consisted of 30 knees. In group A the gap after osteotomy was filled with a synthetic (tricalcium phosphate (TCP)) osteoconductive bone graft (Actifuse Granules®; Apatech Limited, Elstree, Hertfordshire, United Kingdom), while group B received no augmentation. The selection was made by date of operation: patients between July 2004 and April 2009 received no augmentation, whereas between May 2009 and March 2011 synthetic augmentation was performed.

Group A consisted of 11 men and eight women, aged on average 44 years (yrs) (age range 26 to 59 yrs) while group B consisted of 22 men and eight women aged on average 50 yrs (age range 24 to 77 yrs). Group A included two cigarette smokers while group B included eight cigarette smokers.

2.2. Surgical technique

Surgery was performed by two surgeons (senior authors) in accordance with a standard protocol, after accurate preoperative planning of the osteotomy on long leg radiographs (with full weight bearing) [15].

First arthroscopy of the knee joint was carried out for cartilage evaluation [16]. This was followed by a high tibial open wedge valgus osteotomy, performed in accordance with the protocol of Galla and Lobenhoffer [17]. A biplanar osteotomy was performed with a horizontal cut of the posterior two third of the proximal tibia and a 135° angulated cut ascending anteriorly. According to preoperative planning

some patients required correction in the frontal as well as sagittal plane. Missing extension was treated by manipulating the open wedge in that way, that dorsal it was opened slightly more than ventral. For osteosynthesis we used a rigid long-plate fixator with locking bolts (Tomofix®; Synthes GmbH, Solothurn, Switzerland). In group A the osteotomy gap was filled with Actifuse granules, which is a 100% synthetic bone graft and consists of a silicate substituted calcium phosphate. Measurements of the correction angle were performed intraoperatively before and after fixation of the locking plate and documented (Fig. A).

2.3. Postoperative treatment

After surgery all patients were treated in accordance with the same protocol: partial weight bearing with 20 kilograms (kg) for four weeks, no limitation of the range of motion, then X-rays of the knee in both planes were taken and weight bearing was subsequently increased by 10 kg each week until the patient achieved full weight bearing. This postoperative treatment and the rigid long-plate fixator caused no relevant load on the osteotomy gap. Consequently, we avoid load-bearing on our synthetic bone graft, as it is not intended as structural support in the skeletal system [18].

2.4. Clinical and radiographic evaluation

After full weight bearing was achieved follow-up evaluation was performed and bone-healing was assessed six and 12 months after surgery. Bone healing was classified on the basis of clinical and radiological features as complete bone healing leading to the indication for removal of implants after another 12 months or as non-union requiring surgical revision (Figs. B and C).

Postoperative the exact degree of correction can only be measured on a long leg radiograph. Due to radiation exposure this was only performed in patients with suspicious loss of correction clinically or on plain radiographs of the knee. The postoperative treatment had to be modified in some patients because of clinical difficulties such as pain when weight bearing was increased. These patients were reevaluated every one to two weeks. In case of loss of correction or persistent pain, the indication for revision was established after computed tomography (CT)-scan and long leg radiographs. These osteotomies were classified as non-union before the time point of six months postoperatively.

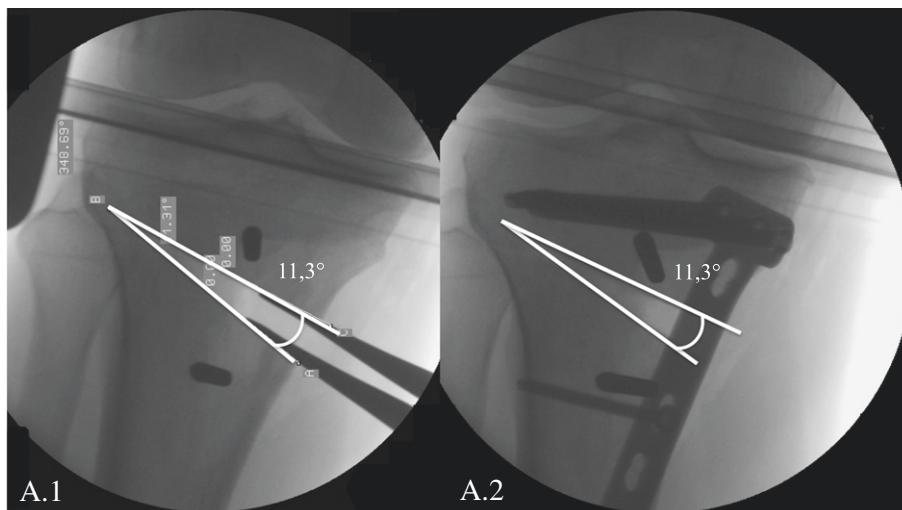


Fig. A. By fluoroscopic control before (A.1) and after (A.2) fixation of the locking plate the measurement of the opening angle is documented with the bone spreader and the Schanz-screws for the correct extension in situ.



Fig. B. Anteroposterior and lateral views of a 50-year old woman, taken nine months after MOWHTO, with an opening angle of eight degrees in the frontal plane and five degrees sagittal correction. The gap was filled with a synthetic bone graft. Bone healing is incomplete. A computed tomography (CT) was performed to verify the fact.

2.5. Statistical analysis

The main goal was to investigate the two groups in terms of bone healing. We compared non-union rates between the two groups. Demographic data (age at operation, gender distribution, smoking rates) and the opening-angle of the osteotomy and the number of extension corrections within the two groups were also investigated and compared. A biostatistical institute was involved in the statistical analysis of the study.

3. Results

Demographic data show a mean age of 44 yrs (range 26 to 59 yrs) in group A and 50 yrs (range 24 to 77 yrs) in group B. This difference was found to be statistically significant (p-value 0.049, t-test) with a higher mean-age in the group without augmentation. Gender-distribution and percentages of smokers and non-smokers are shown in [Table A](#). Statistical analysis showed no statistically significant difference in gender-distribution and distribution of smokers within the two groups. Consequently, the two groups are comparable concerning their demographic data.

All patients completed a minimum follow-up period of eight months (mean 24 months, range 8 to 65 months). In group A (with synthetic augmentation) we found that five out of 19 cases (26%) occurred with a non-union, and in group B (without augmentation) one case out of 30 (3.3%) occurred with a non-union; the difference was statistically significant (p-value 0.027, Fisher test). The mean opening-angle after osteotomy in group A measured 9.6° (range 6 to 18°) and 8.6° (range 4 to 15°) in group B; the difference was not statistically significant (p-value 0.325, Wilcoxon-Mann-Whitney-Test). In group A 13 out of 19 cases (68%) had to be corrected in the sagittal plane, compared to 16 out of 30 cases (53%) in group B. The number of extension corrections is not statistically different in both groups (p-value 0.114, Wilcoxon-Mann-Whitney-Test). The mean extension angle in group A was 6.4° (range 5 to 10) and 5.4° (range 5 to 8) in group B.

Patients with non-union in group A had a mean opening-angle of 11.6° (range 8 to 17°), while the patient with a non-union in group B had an opening-angle of eight degrees. The average time to revision surgery in patients with non-union was 11.9 months (range 2 to 26 months) among those who had undergone synthetic augmentation. The non-union case in the group without augmentation was re-operated after nine months. The exact data of patients with non-union are shown in [Table B](#).

4. Discussion

The aim of the present study was to investigate the usefulness of a synthetic bone graft in terms of bone healing after MOWHTO. Compared to published reports, we registered a rather high rate of non-union cases among our patients who underwent synthetic augmentation. A similar rate of pseudarthrosis has been found by Nelissen [19] who reported about 11 out of 49 (22.4%) cases of pseudarthrosis in MOWHTO after filling the osteotomy gap with Vitoss superficial bone substitute (β -TCP). Our patients without filling material had a non-union-rate of 3.3%, which is similar to the data reported by Warden et al. [20]. The latter study – a review of 182 OWHTO's performed by 21 surgeons – revealed a delayed-union rate of 6.6% and a non-union rate of 1.6%. The three patients with non-union had undergone synthetic augmentation with a coral wedge or iliac crest bone graft with calcium sulfate beads.

Analyzing our cases of non-union retrospectively, we may have to see the indication for surgery in two of these cases critically. One patient with synthetic augmentation had an extremely high opening angle (17°) compared to the average angle in this group (9.6°). The other patient's age at operation (69.8 yrs) in the group without augmentation was a lot higher than the average age at operation (49.5 yrs). However a retrospective multicenter evaluation of 533 cases of MOWHTO performed by Floerkemeier et al. [21] revealed good mid-term results even in older patients with a significant medial cartilage damage.

In a recently published study Saito et al. [22] revealed excellent results in terms of bone healing. They found one case of delayed union and no case of non-union out of 78 cases using synthetic bone graft wedges composed of HA and β -TCP combined with a rigid plate fixation. We assume that only mild varus deformities were investigated, since higher degrees with a varus deformity more than five degrees were



Fig. C. Anteroposterior and lateral views of a 62-year old man, taken one year and 10 months after MOWHTO, with a correction angle of seven degrees in the frontal plane and five degrees in the sagittal plane. No filling material was used for the osteotomy gap. The patient had no pain in the knee joint or tibia, and accomplished full weight-bearing 10 weeks after surgery. The osteotomy was classified as complete bone healing both clinically and radiologically. Removal of the locking plate was planned.

Table A

Demographic data, number of non-unions, extension corrections and opening angle within the two groups are listed.

Group	Number of MOWHTO	Number of non-union	Opening-angle	Gender	Mean age (range)	Number of extension correction	Cigarette smoker
A*	n = 19	n = 5 (28%)	9.6° (6–18°)	8 females (42%) 11 males	44 yrs (26–59 yrs)	n = 13 (68%)	n = 2 (11%)
B**	n = 30	n = 1 (3.3%)	8.6° (4–15°)	8 females (27%) 22 males	50 yrs (24–77 yrs)	n = 16 (53%)	n = 6 (20%)

* Augmentation with synthetic bone graft.

** No augmentation.

excluded in this study. Exactly this group requires an additional augmentation.

Zorzi et al. [23] compared grafted (autologous bone) and non-grafted MOWHTO using a Puddu stainless steel plate as internal fixation. In their randomized clinical trial the authors proved that a graft is not needed when the osteotomy gap is less than 12.5 mm in size. In our population we registered a high range of opening angles and found a statistically significant difference (p-value < 0.001, Wilcoxon–Mann–Whitney-Test) in the opening angle between all 43 cases with complete bone healing (9.1°) and the six cases with non-union (11°). Moreover, the mean opening angle in the five non-union cases with synthetic bone graft was 11.6°, which is statistically significantly higher (p-value < 0,001, Wilcoxon–Mann–Whitney-Test) than the mean opening angle (8.9°) of the other 14 cases in this group. These findings support Zorzi's results, that there is a need for a graft from a certain size of opening angle on, but we were unable to define a specific cut-off-value, which was not aim of this study.

The internal fixation used in our cohort is a special locking plate based on a locking compression plate (LCP) concept. In terms of primary stability this rigid long plate fixator with angle-stable locking bolts yields the best results compared to other types of plates (short spacer plate, short spacer plate with multi-directional locking bolts, long spacer plate with multi-directional locking bolts) [24], especially in cases of fractures of the lateral hinge [25]. The plate-related complications with the implant used in our study were significantly lower compared with a rigid long plate with multidirectional locking options (Peek Power HTO-Plate, Arthrex, FL, USA) [26] or a short spacer plate (Aescula; Braun Korea, Seoul, South Korea) in a two-year follow-up [27]. Though, Roederer et al. [28] claimed that the increased implant stiffness of the locking plate is related with a delayed union after HTO. In a biomechanical experiment as a solution for this problem standard screws were replaced by dynamic screws, which provides a minimal movement underneath the plate and consequently induces an accelerated bone healing. So far this concept lacks its clinical relevance and further clinical studies have to be obtained. Moreover, the review study by Lash [29] revealed no significant difference in terms of bone healing between the different types of plates, although it was only differentiated between locking and non-locking plates.

As special locking plates are available for internal fixation, even interventions performed without interposition material have yielded favorable results. This is confirmed by Staubli's report [30]. Various authors have reported different cut-off values when using filling material: Brinkmann et al. [31] state a cut-off value of >20 mm, while El Assal [32] mention > 14 mm. Although we do agree, that no filling material should

be used below this cut-off, we believe that the addition of TCP into osteotomy gaps does interfere with normal bone healing.

One limitation of the present study was that no preoperative randomization was performed. Our selection was made by the time of operation. After completing 19 cases with synthetic augmentation we stopped using the synthetic bone graft because of the experiences we had with bone healing.

Analyzing the opening angle we found a larger angle in the group who received synthetic augmentation (9.6°) compared to those in whom no augmentation was performed (8.6°), which results in a higher risk for developing a non-union, although the difference was not statistically significant.

Several publications show, that cigarette smoking has a negative impact on bone healing with a higher non-union rate after fractures or osteotomies in cigarette smokers [33]. In our population we had more cigarette smokers in the group without synthetic augmentation, but without statistically significant difference.

We did not find a correlation between the number of extension correction and the occurrence of non-union.

We made no differentiation between non- and delayed-union. We also did not measure the time to bony consolidation with and without synthetic augmentation. According to Aryee et al. [34] bony consolidation did not occur more rapidly when using HA/TCP devices. Performing a randomized radiological and histological study comparing synthetic augmentation with no augmentation after high tibial osteotomy the authors suggest that no HA/TCP wedge should be used in patients with an opening angle less than 10°. These data strongly support our observation of a higher non-union rate when using silicate substituted calcium phosphate as filling material in MOWHTO.

The whole group of different filling materials is very heterogenous, especially the group of synthetic bone substitutes. Due to its osteoinductive, osteoconductive and osteogenetic properties autologous bone is considered to be the best graft in terms of bone healing in a bone healing model [35]. The results of a systematic review study [29] proved, that this model can be transferred to bone healing process after HTO. Different filling materials in a large number of open wedge osteotomies around the knee (3,033) were compared and a statistically significant lower rate of delayed union or nonunion using autograft compared to allograft or synthetic bone substitutes was found. Autograft-bone osteotomies in this cohort occurred with a similar rate of delayed unions or nonunions (2.6%) compared to our group without augmentation (3.3%). Although Gaasbeek et al. [36] showed promising results in his histological study for Beta-Tricalcium-Phosphate in humans after HTO, the results of our study do not recommend its

Table B

Non-union patients from both groups.

	Filling material	Age at operation in years	Smoker	Opening angle in °	Extension angle in °	Gender	Time to re-operation in months
Pat 1	None	69.8	No	8	0	Male	9
Pat 2	Synth. BG*	46.6	No	11	9	Female	19
Pat 3	Synth. BG*	48.5	No	17	0	Male	24
Pat 4	Synth. BG*	44.9	No	11	3	Male	3**
Pat 5	Synth. BG*	48.7	No	11	5	Male	2**
Pat 6	Synth. BG*	49.8	No	8	5	Female	10

* Synth. BG = silicate-substituted synthetic bone graft.

** Reoperated due to early postoperative loss of correction and classified as non-union.

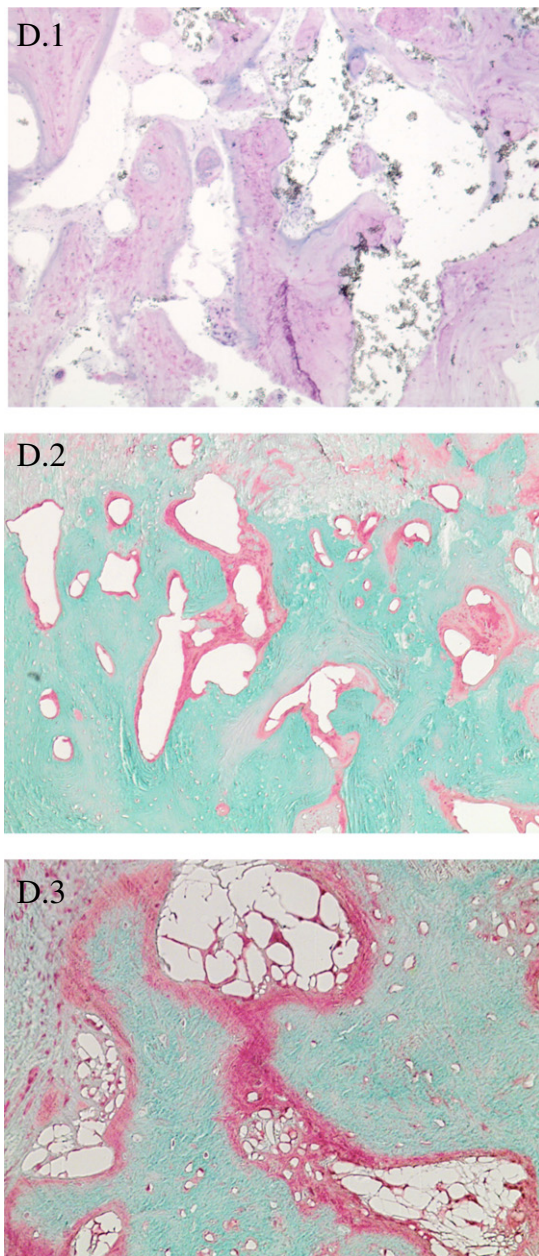


Fig. D. Patient 3 in Table B was re-operated 24 months after MOWHTO because of a non-union. This figure shows undecalcified histology – methacrylate embedding – from the surgical specimen of the revision surgery. D.1: Residual particles (unstained) of the silicate-substituted synthetic bone graft incorporated in new formed bone (Giemsa stain, $\times 4$ obj.). D.2: New formed bone (green) near the pseudarthrosis (upper margin of the slide). Bone surfaces are covered by a thickened layer of osteoid (red), caused by a delay in the bone mineralization (Goldner stain, $4 \times$ obj.). D.3: A reactive fat necrosis within new formed bone near the pseudarthrosis at the left margin (Goldner stain, $10 \times$ obj.).

clinical application after MOWHTO. Obviously, further prospective randomized investigations will be needed to analyze the large number of different bone substitutes or their combinations with platelet-rich plasma (PRP), bone marrow stromal cells or growth factors.

In our cohort one patient with non-union who received bone substitute was analyzed histologically (Fig. D).

The histological investigation was performed by an experienced bone pathologist and strongly supported our findings: silicate substituted calcium phosphate used as a synthetic bone graft in MOWHTO decelerates normal bone healing and may even induce the occurrence of non-union.

We performed no histological investigations on the other cases of non-union, as this was not one of the aims of the study. Further investigations in terms of histological findings have to be performed in the future.

5. Conclusion

In our study patients who underwent synthetic augmentation of the osteotomy gap had a statistically significant higher rate of non-union than those who received no augmentation in MOWHTO. Based on the results of the present study, we no longer use synthetic bone grafts in MOWHTO and do not recommend the use of artificial bone substitute in this setting.

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