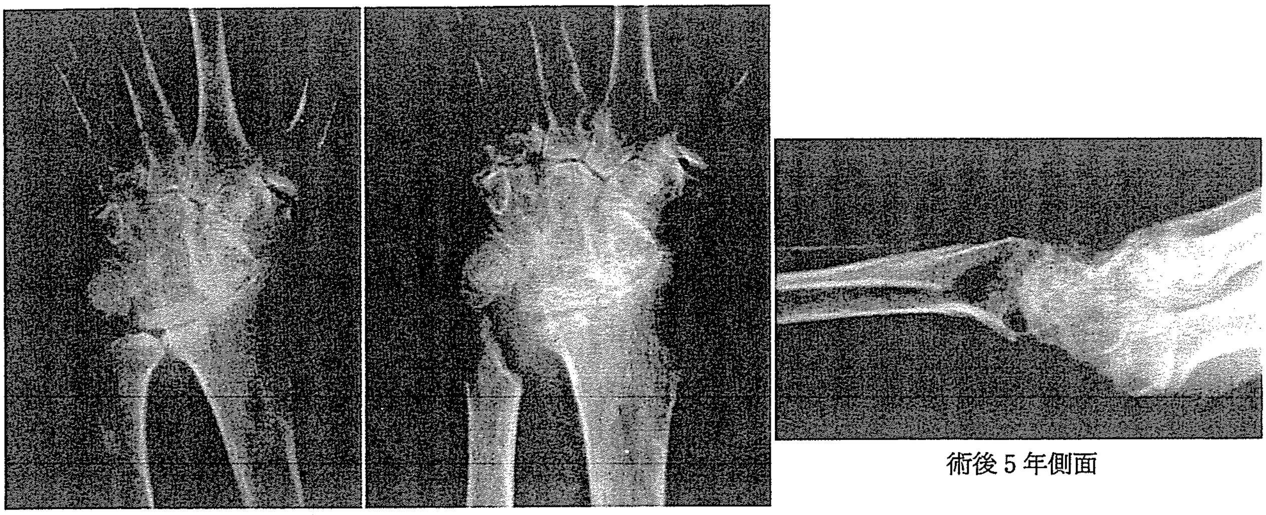


図 6　Hemiresection interposition arthroplasty
62 歳女性，stage Ⅳ。術後 5 年。尺骨遠位端の不安定性はない。

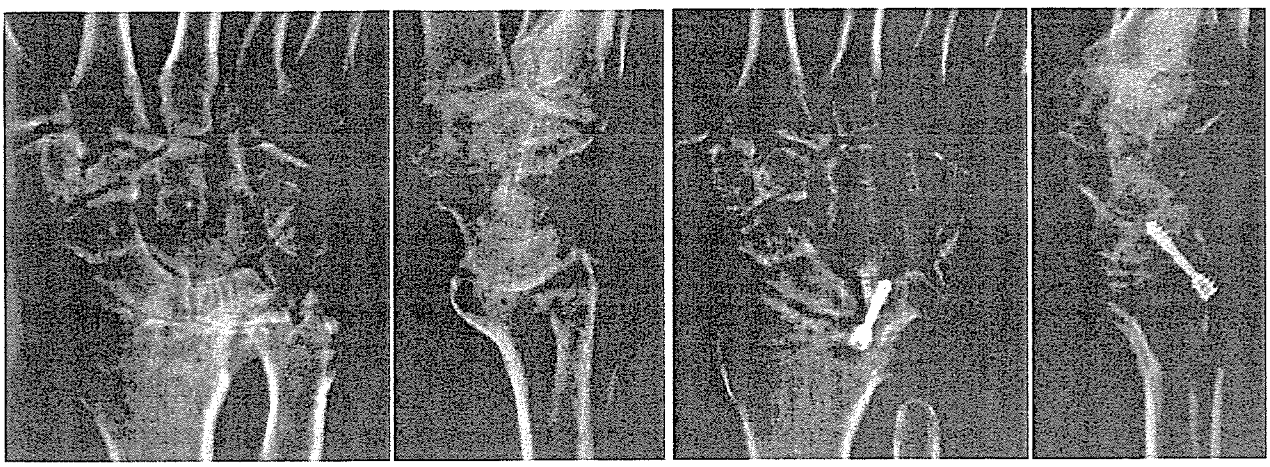
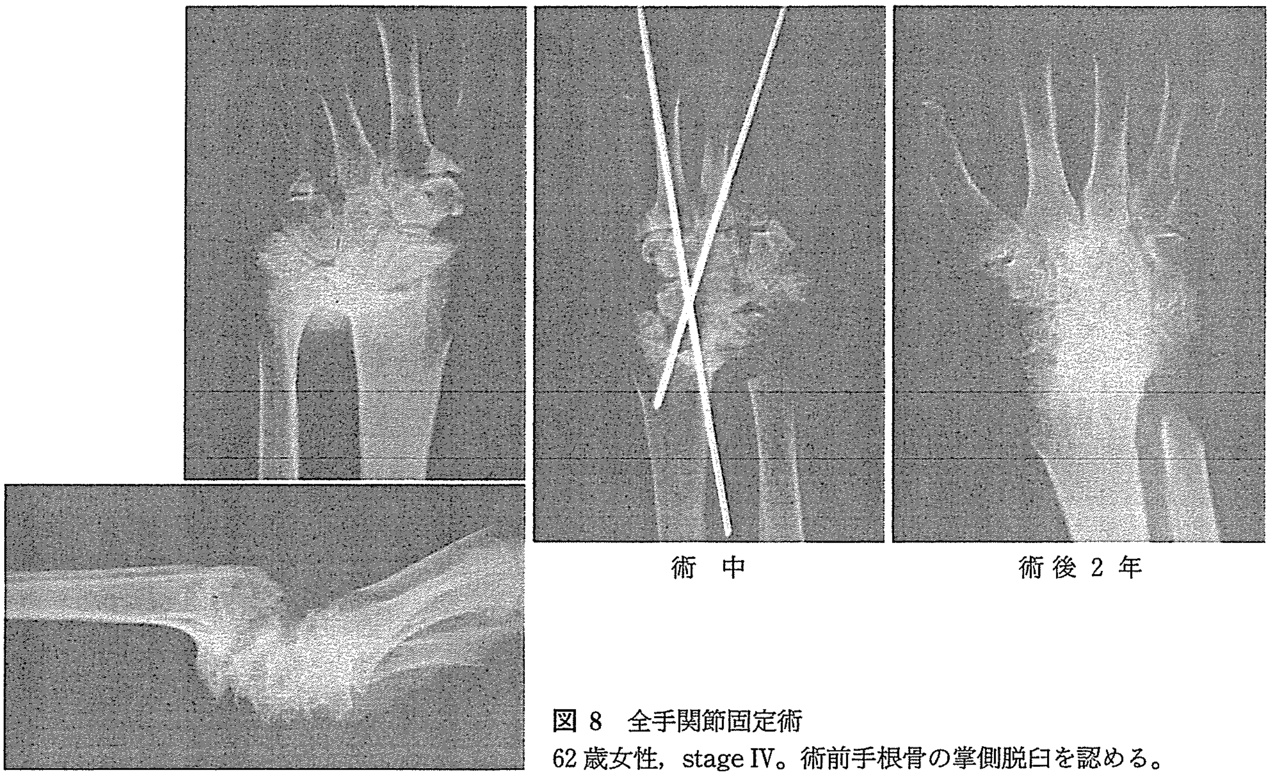


図 7　橈骨月状骨間固定
43 歳男性。術前 stage Ⅲが術後 2 年 stage Ⅲと進行を認めない。伸展-屈曲は術前 40°-60°が術後 25°-50°と軽度低下した。

平均 4 年の調査では伸展が術前 36°から術後 27°，屈曲は術前 36°が術後 26°と各々約 10°の低下を認めたのみであった。また Stanley ら[6]の術後評価でも Excellent が 64%，Good が 36%と良好であり，X 線像での病期の進行を認めなかった[7]。Darrach 法単独では X 線像での病期の進行を認める例があり，橈骨月状骨間固定術の追加はより安定した手関節の獲得と破壊の進行を防ぐ可能性があると思われ，極めて有用な方法である。

2．全手関節固定術

手関節リウマチでは手根中央関節の関節破壊は痛みの原因となることが少なく，全手関節固定術が適応となる場合は少ないと考えられる。また手関節可動域は腱の滑動（excursion）の増加にとっ



術　前　　術　中　　術後 2 年

図 8　全手関節固定術
62 歳女性，stage Ⅳ。術前手根骨の掌側脱臼を認める。

て極めて重要であり，とくに手指伸筋腱の腱断裂を伴う例では全固定術により十分な腱の滑動が得られず，手指の運動機能の損失が大きくなる。また同側の肩，肘関節にも機能障害が存在する場合は全固定術によってADLが著明に障害されてしまう。したがって全固定術が適応となるのは全手関節の破壊があり，同側の肩，肘，手指の機能が温存されている活動性の高い若年者や手関節伸筋腱群が断裂した有痛性の高度の屈曲拘縮が存在する場合に限られる。

手関節の固定肢位に関しては意見の分かれるところである。筆者らは屈曲伸展および橈尺屈中間位での固定を原則としているが，両側例では片側は中間位で，対側は20°程度の屈曲位で固定するのがよい。

手術方法も様々な手技が報告されている。筆者らはCarroll ら[8)]の方法に準じて行っている。手根骨背側をリューエルなどで切除したのち，腸骨より皮質海綿骨をウサギの顔のように採型し，両方の耳に該当する部分は第 2，3 中手骨基部髄腔へ，顔の顎の部分は橈骨遠位髄腔へ挿入する。さらに 2 本の 1.8 mm の Kirschner wire を腸骨背側で交叉させて第 2，3 中手骨と橈骨間を固定する。これにより移植骨を手根骨に押さえ込むように強固に固定することができる（図 8）。必要であれば 3 本目の鋼線を追加する[9)10)]。

3．人工関節置換術

同側の肩，肘，手指の破壊が存在し，手関節の可動域が必要な活動性の低い例で適応となるが，現在のところ長期にわたり安定した成績は得られていない。

1967 年に Swanson が手関節に対して flexible なシリコン人工関節（図 9）を応用したが，シリコン滑膜炎やインプラントの破損など大きな問題点があった[11)]。1970 年代後半に全人工関節として Meuli[12)]や Volz[13)]などの ball and socket 人工関節が開発され臨床応用された。1～2 年の短期成績は良好であったが，5 年前後の長期では遠位コン

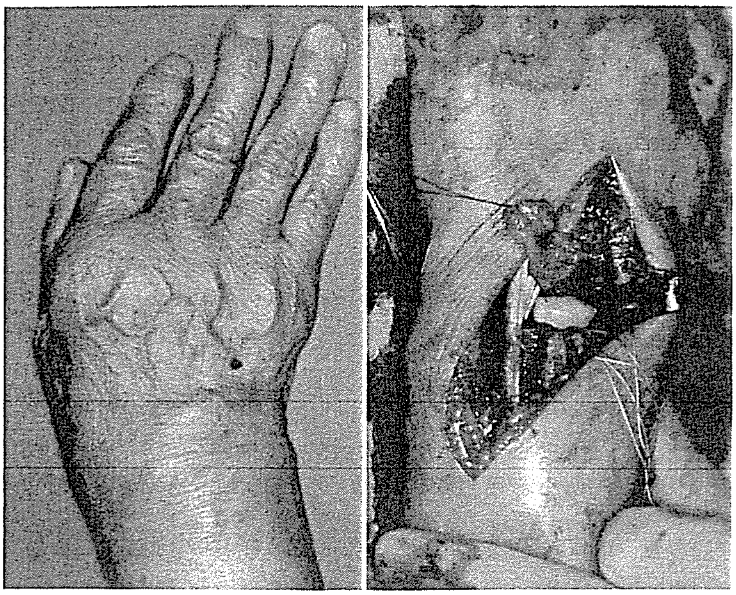


図 9　Swanson インプラント
60 歳女性，stage IV。

ポーネントのゆるみや脱臼などを生じ，failure rate は 30%前後にのぼると報告されている。また骨切除量が多く，手関節固定術など salvage 手術が困難であることも大きな問題点である。

1983 年より Mayo Clinic で開発され使用されている biaxial wrist prosthesis の 5 年以上の成績の報告では 46 例中 8 例で遠位コンポーネントのゆるみ，1 例で脱臼が生じたとしており[14]，成績は向上しているものと考えられる。今後さらに手技および機種の改善による長期成績の向上が望まれる。

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Summary

Surgical treatment for rheumatoid arthritis of the wrist

Surgical treatment for rheumatoid arthritis of the wrist is detailed. Synovectomy of the wrist joint is effective for the prolonged synovitis that resists medicinal treatment with retained joint space. Darrach, Sauvé-Kapandji and hemiresection interposition arthroplasty are indicated for painful forearm rotation due to the destruction of distal radio-ulnar joint. Limited wrist fusion, especially radiolunate fusion is a reliable method for pain relief and the stability of the joint. Each operative intervention should be selected according to the radiographic stages and demands of the patients, considering the condition of the other joints.

Jun-ichi ISHIKAWA et al, Hokkaido Univ., Hokkaido

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II
代表的疾患のリハビリテーション

1．上肢・肩甲帯

5）手関節周辺外傷*

石川淳一　三浪明男**

[整形外科 56 巻 8 号：940～944，2005]

◎ はじめに ◎

手関節周辺の外傷としては橈骨遠位端骨折，舟状骨骨折をはじめとする手根骨骨折，月状骨周囲脱臼，三角線維軟骨（TFC）損傷，遠位橈尺関節（DRUJ）脱臼などが代表的である．これらの外傷に対するリハビリテーションにあたっては，まず手関節の複雑なバイオメカニクスに対する知識が必要であると考える．本稿ではじめに手関節のバイオメカニクスについて触れたあと，手関節外傷全般および先に列挙した代表的外傷に対する理学療法の実際について述べることとする．

I．手関節のバイオメカニクス

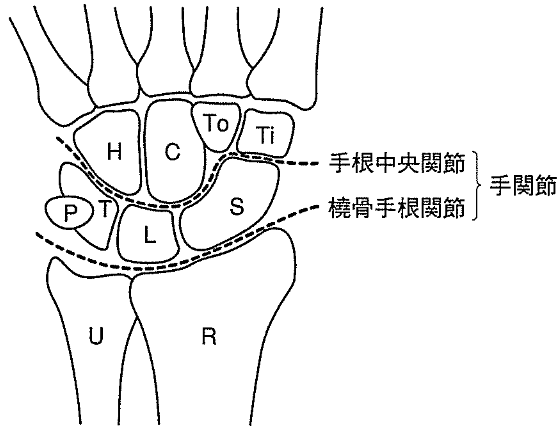

図 1．手関節の骨格構造．R：橈骨，U：尺骨，S：舟状骨，L：月状骨，T：三角骨，P：豆状骨，H：有鉤骨，C：有頭骨，To：小菱形骨，Ti：大菱形骨

手関節は 8 つの手根骨および橈尺骨により構成される．手根骨は近位手根列として舟状骨，月状骨，三角骨の 3 つがあり，橈骨と橈骨手根関節（radiocarpal joint）を形成する．豆状骨は尺側手根屈筋腱付着部に存在し種子骨と考えられ，三角骨とのみ関節面を有する．遠位手根列は大菱形骨，小菱形骨，有頭骨，有鉤骨より構成され，近位手根列とのあいだで手根中央関節（midcarpal joint）を形成する（図 1）．手関節運動は中手骨基部に付着する橈尺側の手根伸筋，屈筋腱により作動し，遠位手根列から近位手根列へ伝わり，それぞれの手根骨の解剖学的形態や手関節の諸靱帯の制御により複雑かつ精巧な運動がもたらされる（図 2）．手関節運動は主に掌背屈および橈尺屈であり，橈骨手根関節，手根中央関節の両方が関与する．それぞれの関節が掌背屈運動に関与する割合は，一般に背屈で橈骨手根関節：手根中央関節＝6：4，掌屈では逆に 4：6 と考えられている．また橈尺屈運動のうち橈屈は約 70％が手根中央関節において行われ，尺屈ではそれぞれ約 50％である．近位手根列は橈屈では尺側移動とともに

Key words：wrist, kinematics, physiotherapy

* Rehabilitation after traumatic injuries of the wrist

** J. Ishikawa, A. Minami（教授）：北海道大学整形外科（Dept. of Orthop. Surg., Hokkaido University, School of Medicine, Sapporo）.

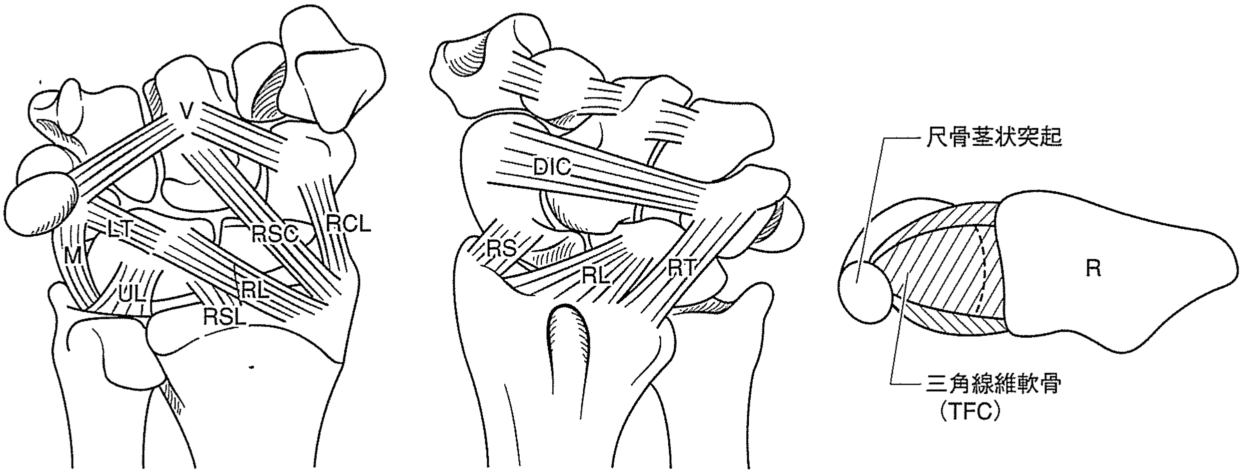

図 2．手関節の靱帯構造．それぞれ起始および付着する骨の頭文字にて呼称する．V：V 靱帯，M：メニスクス，LT：月状三角骨靱帯，UL：尺骨月状骨靱帯，RSL：橈骨舟状月状骨間靱帯，RL：橈骨月状骨靱帯，RSC：橈骨舟状有頭骨間靱帯，RCL：橈側側副靱帯，RS：橈骨舟状骨靱帯，RT：橈骨三角骨靱帯，DIC：背側手根間靱帯

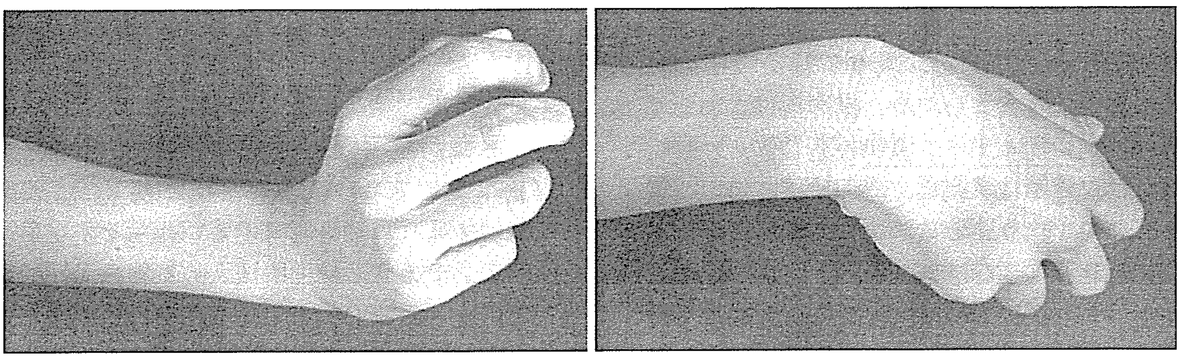

図 3．Dart throwers motion．手関節橈背屈から掌尺屈への運動

掌屈し，逆に尺屈では橈側移動するとともに背屈する．遠位手根骨同士は強固に連結されており相互の運動はわずかであるが，近位手根列間すなわち舟状骨月状骨間，月状骨三角骨間は手関節運動に伴いある程度の動きが生じる．近位手根列のうち舟状骨は mechanical link としてもっとも重要であり，手関節動作筋によりもたらされる遠位手根列の動きは舟状骨を介して近位手根列に伝わる．このことより舟状骨の動きは近位手根列の中でもっとも大きく，手関節背屈では舟状骨は月状骨に対して約 20°背屈し，手関節掌屈では 10°～15°掌屈する[1]．したがって，手関節の靱帯でもっとも損傷頻度が高いのが舟状骨月状骨間靱帯である．もともと舟状骨長軸は掌屈しているうえに，遠位手根列からの軸圧により掌屈する力が加わっている．一方月状骨は形態的に側面からみて背側が薄く，掌側が厚い非対称の三日月形のため，遠位手根列からの軸圧は月状骨を背屈させる力となる．月状骨（周囲）脱臼などで舟状骨月状骨間靱帯が広範囲に損傷されたり，舟状骨偽関節により舟状骨の動きが月状骨に伝わらなくなることで，月状骨が背屈，舟状骨が掌屈する，いわゆる dorsiflexed intercalated segment instability (DISI) 変形が発生することとなる．

最近では手関節の掌背屈運動に関して，矢状面ではなく投げ矢面 (dart throwers plane) での運動がより生理的であることが証明されてきている[2]．これは橈背屈から掌尺屈の運動（いわゆるダーツを投げるさいの運動）であり，日常での手関節の動きはほとんどこの面での動きであるといってもよいかもしれない（図 3)．

筆者らは新鮮凍結死体を用いた手関節の運動解析にて，矢状面と投げ矢面での手関節運動を比較した．その結果，投げ矢面では矢状面に比し，手根中央関節の動きが橈骨手根関節の動きより大きくなり，また舟状骨月状骨間の動きは少なくなることがわかった[1]．このことは橈骨遠位端骨折や舟状骨月状骨間損傷後の関節可動域（ROM）訓練として，投げ矢面での運動がより安全で有効であることを示していると考えられる．

DRUJは凹面をなす橈骨の尺骨切痕（sigmoid notch）と凸面の尺骨頭による関節であり，前腕の回内外運動にさいし，橈骨頭と尺骨茎状突起基部を結ぶ線を回転軸として尺骨頭周囲を橈骨が回旋する．その安定性に関しては骨性の関与は少なく，関節包，三角線維軟骨複合体（TFCC），尺側手根伸筋腱，骨間膜，方形回内筋など，主に周囲軟部組織が安定化機構として重要である（図2）．尺骨切痕の曲率は尺骨頭の曲率より大きいため，回内外にさいしては回転運動に加えすべり運動が生じる．一般に回外では尺骨頭は掌側に，回内では背側に位置する．このすべり運動は前述した軟部組織により制動される．このうちTFCはDRUJの安定性にもっとも重要であり，尺骨茎状突起基部付着部のTFC断裂はDRUJの不安定性をもたらす．

II．手関節外傷後のリハビリテーション

1 急性期

手関節周囲の外傷後は当然ながら手関節の腫脹をきたすが，加えて手部および手指にまで浮腫が及ぶ．外傷直後あるいは手術直後の急性期はギプスシーネあるいはスプリントによる手関節部の固定が行われる．腫脹をいかに抑えるかが急性期のリハビリテーションにおいてはきわめて重要であり，三角巾による患肢挙上と局所のクーリングが必要である．三角巾は患肢挙上のため広く行われるが，患者にはあまり三角巾に頼らず，常に心臓より高い位置で手を挙上し，肩，肘，手指の自動運動を積極的に行うよう指導する．このことは上肢の外傷後に起りやすいcomplex regional pain syndrome（CRPS）の発生防止の点でもきわめて重要である．外固定の遠位の範囲は手関節のみとすることは当然であり，手指が完全に屈曲・伸展できることを確認する．中手指節（MP）関節は伸展拘縮を起しやすく，完全屈曲可能とするためには外固定は手掌中央皮皺線を越えないよう注意する．また近位指節間（PIP）関節は屈曲拘縮を起しやすく，拘縮が完成してしまうと改善が困難となるため，早期より他動的に完全伸展させる必要がある．さらに母指の内転拘縮にも注意が必要である．腫脹の消退のためには自動運動が重要であり，テニスボールなどなるべく軟らかいものを使って積極的に行わせる．ゆっくりと最大屈曲させ，屈曲位をしばらく保持するように指導する．数時間ごとに10分など時間を決めて行ってもらうと有効である[3]．

2 回復期

外傷の種類にもよるが，外固定期間は通常4〜6週であり，その後手関節のROM訓練を開始する．最初は痛みのない範囲での自動運動が中心であり，物理療法として気泡浴や渦流浴を行う．自宅でも入浴時などの自動運動を指導する．ROM訓練後の腫脹の状況をみつつ，腫脹の増強がなければ徐々に他動でのROM訓練を始める．もし訓練後腫脹，熱感の増強があるようなら無理な継続はせず，冷水中での自動運動や訓練後のアイシングを行う．手関節のROM訓練は掌背屈が中心であるが，前述した投げ矢面でのROM訓練が運動生理学的にもっとも安全で有効であると考えられる．獲得ROMの増加と平行して手関節伸筋・屈筋の筋力訓練を行う．

III．代表的手関節外傷疾患とリハビリテーションの注意点

1 橈骨遠位端骨折

高齢者など骨萎縮がすすんだ例では，手をついて転倒したさいなどに容易に本骨折が発生する．一般に手関節背屈位で転倒したさいは遠位

表 1. 橈骨遠位端骨折保存的治療のリハビリテーション

	外固定	物理療法	運動療法
0〜2 週	肘上あるいは sugar tong 型のシーネ (三角巾固定)	患肢の挙上，クーリング	肩，手指の ROM 訓練
2〜4 週	肘下（手関節のみ）	手指のマッサージ	肘の屈曲・伸展運動 前腕の回内外運動 ゴムボールを用いたグリップ運動
4〜6 週	外固定除去 夜間，外出時にスプリント固定	気泡浴，渦流浴 手指のマッサージ	手関節の ROM 訓練 (自動運動中心に) [dart throwers motion]
6〜8 週	完全フリー	気泡浴，渦流浴	手関節の他動 ROM 訓練 (全 ROM) 手関節屈筋，伸筋の筋力訓練

骨片が背屈転位（Colles 骨折）し，逆に掌屈位で転倒したさいは掌屈転位（Smith 骨折）する．高齢者では遠位骨片が粉砕し，関節内骨折となることが多い．Colles 型で粉砕の程度が少ない単純な関節外骨折では，徒手整復により良好な整復位が得られた場合はギプス固定による保存的治療が選択される．表 1 に一般的な保存的治療とリハビリテーションの流れを示す．外固定は腫脹の強い受傷後早期は主に sugar tongs 型のシーネ固定とし，腫脹の消退後ギプス固定を手関節中間位で MP 関節は完全にフリーとして施行する．橈骨遠位端骨折は高齢者に多く，手指の拘縮をきたしやすい．前述したように手指の自動・他動運動はなるべく早く指導し，腫脹，浮腫と手指の拘縮の防止に努めることが必要である．自動運動は腫脹の消退には有用であるが，強くグリップさせるような自動運動は骨折部での短縮変形を起す危険性があることにも留意する．DRUJ の不安定性や DRUJ への関節内骨折を認める場合は 2 週間肘上まで固定し，その後肘下に変更して回内外運動を許可する．回内外の ROM 訓練は肘を体幹に固定した状態で行う．一般に背屈転位型では尺骨頭の掌側転位をきたしやすく回内制限を，掌屈転位型では尺骨頭は背側転位し回外制限をきたしやすいことを念頭におく．骨癒合の状況にもよるが，通常はおよそ 6 週間で外固定を除去し，手関節の ROM 訓練を始める．

手術的治療としては経皮鋼線固定，プレート固定，創外固定などがある．創外固定は粉砕の強い例などに用いられ，手関節をまたいで固定するタイプ（bridging type）と最近では手関節をまたがないタイプ（non-bridging type）がある．高齢者で bridging type を使用した場合，過牽引を加えると，伸筋および屈筋腱の緊張が増加し，MP 関節伸展，PIP 関節屈曲拘縮をきたしやすい[4]．一方，non-bridging type では早期の手関節運動が可能となる利点があるが，骨折の粉砕例ではその固定力にはなお問題があると思われる．

2 舟状骨骨折

舟状骨骨折は若年者から壮年にかけて活動性の高い年齢層に多く，手関節背屈位を強制されたさいに発生する．受傷後早期の X 線像では骨折線がはっきりしないことが多く，腫脹，嗅ぎタバコ窩や舟状骨結節部の圧痛がある場合は 1〜2 週間の外固定を行ったのち，再度 X 線像にて骨折の有無の確認を行う．通常の正面像，側面像では診断がむずかしく，舟状骨の長径がもっとも長く撮影されるように手を握って手関節尺屈位での正面像が有用である．舟状骨は主に遠位から骨内に侵入する橈骨動脈の枝によりほとんど栄養されているため，血行に乏しく骨癒合が得にくく偽関節となりやすい．

転位がない場合はギプスによる保存的治療が選択される．ギプス固定の範囲については議論のあるところではあるが，一般には肘下で母指は MP 関節まで含めて固定する thumb spica cast がもっとも多く用いられている．固定期間は 6〜8 週間であり，その後手関節の ROM 訓練を開始する．骨癒合が得られれば通常ほぼ正常な ROM 獲得が可能である．

3 月状骨（周囲）脱臼

高所からの転落などで手関節が背屈強制され，さらに手根骨に回外強制が加わり受傷する．手関節部骨折の中ではもっとも高エネルギーによる外傷である．月状骨周囲の靱帯がすべて損傷されると，月状骨の背側にほかの手根骨が脱臼し月状骨周囲脱臼の形となる．あるいは月状骨掌側部の靱帯脆弱部であるPoirie腔より月状骨が掌側に脱臼し月状骨掌側脱臼の形となるが，両者はほぼ同じ病態と考えられている．舟状骨骨折を合併する経舟状骨月状骨周囲脱臼がもっとも多い．手関節の疼痛と腫脹が主である．著明な腫脹のため外見上は脱臼による変形が目立たないことが多い．新鮮例ではなるべく早期に整復を試みる．整復後に手根骨の配列を確認する．舟状骨月状骨間の離開，舟状骨の掌屈変形，月状骨の背屈変形が残存する場合が多く，筆者らは積極的に背側より舟状骨月状骨間靱帯の修復を行い，手根骨配列は鋼線固定にて保持する．腫脹が強いため手指のROM訓練，自動でのグリップ訓練は積極的に行ってもらう．6～8週間の外固定ののちROM訓練を開始する．前述したように投げ矢面での掌背屈は舟状骨月状骨間の動きが少なく，最初は主にこの面でのROM訓練が安全である．その後徐々に全可動方向での訓練を行う．高エネルギー外傷であり，ROM制限が残りやすいことに留意する．

4 TFCC損傷

TFCC損傷は転倒などにより手関節が背屈位，回内位で軸圧が加わったさいや繰り返す回内外ストレスにより発生する．TFCCの外傷性断裂は断裂部位により分類されている[5]．治療法として2～3ヵ月の保存的治療抵抗例では手術的治療が適応となり，手関節鏡の進歩により鏡視下手術が一般的に行われるようになった[6]．保存的治療としては，安静のため手関節中間位にてギプスシーネ固定を2～3週間施行する．シーネ除去後は取りはずし可能なスプリント固定やTFCC用のブレースを装着させる．物理療法として温熱治療を行い，回内外および掌背屈の自動運動を開始する．痛みなく自動運動が可能となった段階で他動運動，ストレッチングおよび筋力訓練を指導する．スポーツはその種類にもよるが，3ヵ月後より徐々に許可する．手術的治療として部分切除を行った場合は，1～2週間の肘下から手関節の外固定を行う．縫合術を行った場合は2週間の肘上までの固定後，さらに肘下での固定を2週間行う．外固定除去後のリハビリテーションは保存的治療と同様であるが，縫合術では腫脹が長期に及ぶため，ROM訓練は痛みの状態を観察しながら施行する．

おわりに

手関節周囲外傷後のリハビリテーションについて述べた．手関節は骨・靱帯が解剖学的に複雑な構造を呈し，そのバイオメカニクスについての知識とおのおのの手関節外傷のメカニズム，特徴についての理解も必要である．また手関節外傷後のリハビリテーションにあたっては，上肢とくに手指の機能の維持を常に考慮することが重要であると考える．

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Influence of Distal Radioulnar Joint Subluxation on Restricted Forearm Rotation After Distal Radius Fracture

Jun-ichi Ishikawa, MD, PhD, Norimasa Iwasaki, MD, PhD, Akio Minami, MD, PhD, *Sapporo, Japan*

Purpose: To analyze the influence of subluxation of the distal radioulnar joint (DRUJ) on restricted forearm rotation after distal radius fracture.

Methods: Twenty-two cases of healed unilateral distal radial fracture with restricted forearm rotation were included in the study. The subluxation of the DRUJ was evaluated using helical computed tomography scan at neutral, maximum pronation, and maximum supination and presented as the percent displacement of the ulnar head in both the injured and uninjured sides. The radiographic parameters of palmar tilt, radial inclination, dorsal shift, radial shift, and ulnar variance were measured on plain x-ray films and the rotational deformity of the distal radius was evaluated from the computed tomography scan. The differences of each radiographic parameter from the uninjured side were calculated. The relationships between the restricted forearm rotation and the percent displacement of the ulnar head and each of the radiographic parameters were analyzed statistically.

Results: When forearm pronation was restricted the ulnar head was located palmarly at neutral, maximum supination, and maximum pronation with severe dorsal tilt of the distal radius. When supination was restricted the ulnar head was located dorsally at maximum supination with severe ulnar-positive variance.

Conclusions: The subluxation of the DRUJ was related to restricted forearm rotation. The radiographic parameters of palmar tilt and ulnar variance showed an adverse influence on the position of the ulnar head at the DRUJ, which might lead to restricted forearm rotation after distal radial fracture. (J Hand Surg 2005;30A:1178–1184. Copyright © 2005 by the American Society for Surgery of the Hand.)

Type of study/level of evidence: Therapeutic, Level IV.

Key words: Distal radius fracture, forearm rotation, subluxation, distal radioulnar joint.

Restricted forearm rotation after distal radial fracture is a common problem that occurs because of subluxation of the distal radioulnar joint (DRUJ) and contracture of the surrounding soft tissues including the capsule of the DRUJ, triangular fibrocartilage, and interosseous membrane.[1] It recently was stressed that the congruity and stability of the DRUJ could be achieved when performing corrective osteotomy for malunion of the distal radius.[2–6]

Evaluation of the subluxation of the DRUJ is difficult to achieve by plain x-rays because subtle forearm rotation can lead to misinterpretation of the ulnar

From the Department of Orthopedic Surgery, Hokkaido University School of Medicine, Sapporo, Japan.

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Corresponding author: Jun-ichi Ishikawa, MD, PhD, Department of Orthopedic Surgery, Hokkaido University School of Medicine, Kita-15, Nishi-7, Kita-ku, Sapporo 060-8638, Japan; e-mail: ishi-j@med.hokudai.ac.jp

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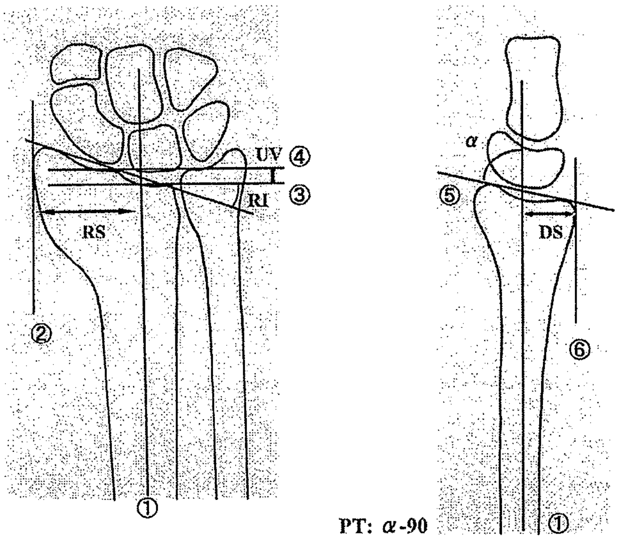


Figure 1. Each radiographic parameter was calculated as the difference between the injured and uninjured sides. (1) Longitudinal axis of the radius. (2) Line tangential to the most radial edge of the distal radius parallel to the longitudinal axis of the radius. (3) Line perpendicular to the longitudinal axis of the radius at the level of the ulnar margin of the distal radial articular surface. (4) Line perpendicular to the longitudinal axis of the distal radius at the level of the distal ulnar articular surface. (5) Line connecting the dorsal and palmar margins of the distal radial articular surface. (6) Line tangential to the most dorsal edge of the distal radius parallel to the longitudinal axis of the radius. PT, palmar tilt; RI, radial inclination; RS, radial shift; DS, dorsal shift; UV, ulnar variance.

head position. Computed tomography (CT) is a reliable radiographic tool and several investigators have advocated different methods for evaluating the subluxation with a CT scan.[7–12] There have been no reproducible methods, however, to date. Recently Lo et al[13] reported a new quantifying method to detect the subluxation of the DRUJ in a CT scan, which they termed the *radioulnar ratio.* They compared this method with other evaluation techniques (epicenter method, congruency method, and Mino criteria[10,11]) and proved the validity of their method. We have used a similar method for evaluation with a CT scan and presented it as percent displacement of the ulnar head relative to the sigmoid notch of the radius.

This *in vivo* study was designed to observe the relationship between restricted forearm rotation and subluxation of the DRUJ at neutral rotation, maximum supination, and maximum pronation and the radiographic parameters after healed distal radial fracture.

Materials and Methods

Twenty-two consecutive cases of healed unilateral distal radial fracture with restricted forearm rotation (pronation or supination) were included in the study. The initial fractures were extra-articular dorsally angulated fractures. Fractures that extended into the DRUJ and radiocarpal joint were excluded. Cases that showed restriction of both pronation and supination also were excluded to detect the influence of DRUJ subluxation on limited pronation or supination separately. The average time after the injury was 16 months (range, 6–36 mo). There were 20 women and 2 men with a mean age of 68 years (range, 29–84 y). The initial treatments for the fracture consisted of manual reduction with splint fixation (13 patients), intrafocal percutaneous pin fixation (8 patients), and external fixation (1 patient).

Palmar tilt, radial inclination, dorsal shift, radial shift of the distal radius, and ulnar variance were measured on plain posteroanterior and lateral x-rays after the fracture was healed and the differences from the uninjured side were calculated. Dorsal shift was defined as the distance between the line of the longitudinal axis of the radius and the line tangential to the most dorsal edge of the distal radius on lateral x-ray. Radial shift was defined as the distance be-

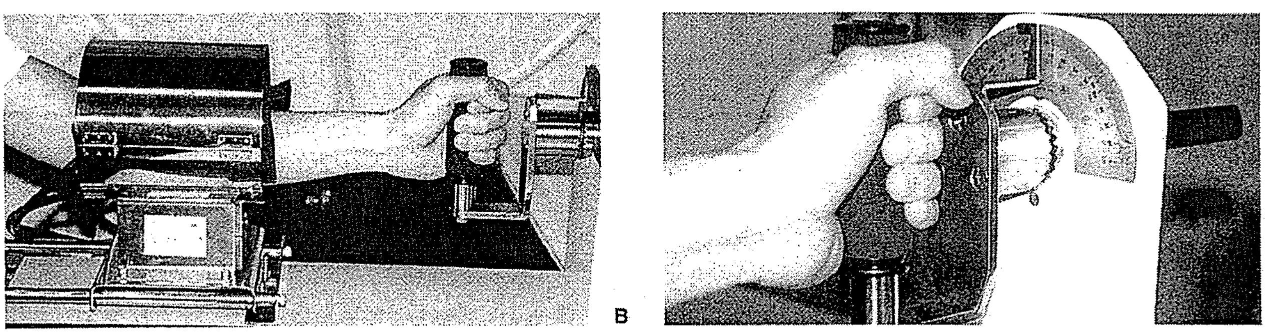
A  B

Figure 2. (A) Each patient's forearm was fixed to a custom-designed apparatus using a tourniquet band with 60° of elbow flexion. (B) The handle that gears with the protractor was locked to keep the position of forearm rotation (neutral rotation, maximum pronation, and maximum supination).

tween the line of the longitudinal axis of the radius and the line tangential to the most radial edge of the distal radius on posteroanterior x-ray (Fig. 1).[14] The ranges of each parameter were as follows: palmar tilt, −43° to 5° (average, −14°); radial inclination, −19° to 5° (average, −4°); dorsal shift, −3 to +7 mm (average, +2 mm); radial shift, −2 to +9 mm (average, +2 mm); and ulnar variance, +1 to +6 mm (average, +3 mm). In 3 cases the palmar tilt was greater than in the uninjured side because of excessive reduction of the dorsally tilted distal radial fragment during the initial treatment for the fracture.

Subluxation of the DRUJ was evaluated using helical CT scan (Xvision, Toshiba, Japan). The patients were in the prone position and the forearm was fixed to a custom-made apparatus using a tourniquet band to exclude the influence of shoulder rotation with 60° of elbow flexion (Fig. 2A). Patients were instructed to grasp the pole of the apparatus for exact positioning of the forearm rotation (Fig. 2B). To exclude rotation at the radiocarpal joint patients performed the active forearm rotation without passive forceful rotation. The degree of restricted rotation was examined using a goniometer attached to the apparatus and was confirmed on the CT scan by comparing the position of the groove for the extensor carpi ulnaris tendon in the ulnar head relative to the radius between the injured and uninjured sides.

The scan was begun from the middle of the forearm through the DRUJ at intervals of 3 mm with the forearm at neutral rotation, maximum pronation, and

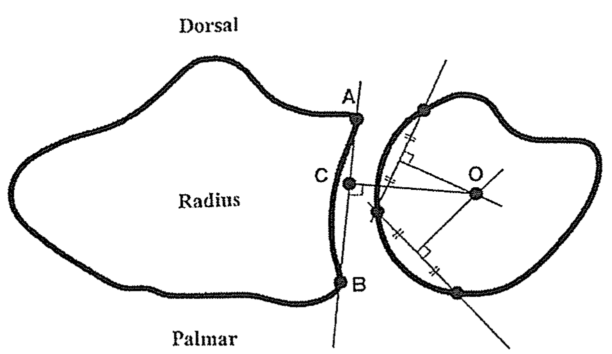


Figure 3. Percent displacement. The center of the ulnar head (O) was determined by selecting 3 points on an outline of the ulnar head. A perpendicular line was drawn to the line connecting the dorsal and palmar ridges of the sigmoid notch of the radius. The length of the palmar segment of the line (BC) was divided by the total length (AB) and presented as the percent displacement of the ulnar head. BC/AB × 100 (%) - 50 (%) was used to express the position of ulnar head; positive = palmar; negative = dorsal.

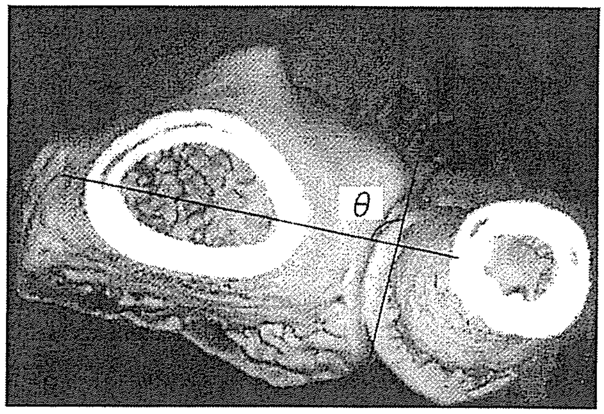


Figure 4. Pronation–supination deformity of the distal radius was determined by measuring the angle (θ) between the transverse axis of the radial shaft proximal to the site of malunion and a line tangential to the sigmoid notch of the radius from the helical CT scans at neutral rotation. The difference of the angle from the uninjured side was determined as the pronation–supination deformity. Positive = supination; negative = pronation.

maximum supination. A helical CT scan of the uninjured side also was performed with the same rotational positions. Subluxation of the DRUJ at neutral rotation, maximum supination, and maximum pronation was evaluated according to the radioulnar ratio proposed by Lo et al.[13] The forearm rotational axis is a line connecting the fovea of the ulnar head distally and the center of the radial head proximally. The distal radius rotates around the ulnar head at the DRUJ. In a clinical situation, however, subluxation or dislocation at the DRUJ usually would be expressed by the position of the ulnar head. Therefore subluxation of the DRUJ was evaluated by the percent displacement of the ulnar head relative to the radius.

We chose the slice of the CT scan in which the ulnar head and the sigmoid notch of the radius had the largest outline of subchondral shape. If different slices were chosen for each bone then they were superimposed on each other and a 2-dimensional evaluation was performed. The center of the ulnar head was determined by selecting 3 points on an outline of the ulnar head. A line was drawn perpendicular to the line connecting the dorsal and palmar ridge of the sigmoid notch of the radius. The length of the palmar segment of the line was divided by the total length and presented as the percent displacement of the ulnar head relative to the radius (Fig. 3). The measurement was repeated 3 times and averaged at each rotational position.

The pronation–supination deformity of the distal

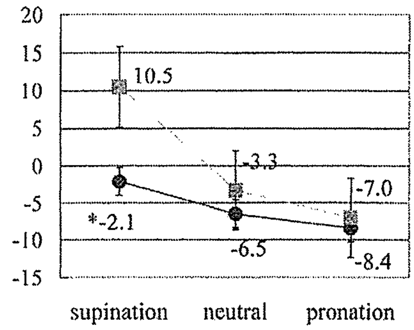


Figure 5. The percent displacement of the ulnar head in group S (restricted supination). The ulnar head on the injured side was located dorsally at supination compared with the uninjured side. *p < .05, paired *t* test between the injured and the uninjured sides. ●, Injured; ■, uninjured.

radius was added as a radiographic parameter, which was obtained by measuring the angle between a transverse axis of the radial shaft proximal to the fracture site and a line tangential to the sigmoid notch of the radius in a 3-dimensional reconstruction of the helical CT scan at neutral rotation according to the method reported by Prommersberger et al[15] (Fig. 4). The difference of the angle from the uninjured side was determined as the pronation–supination deformity (range, −15° to +11°; average, −6°; supination: +, pronation: −).

The patients were divided into 2 groups according to the direction of the limited forearm rotation: pronation or supination. The pronation was restricted (average, 24°; range, 15°–40°) in 11 patients (group P). The supination was restricted (average, 31°; range, 20°–50°) in 11 patients (group S). The percent displacement at each rotational position was compared between the injured and uninjured sides in both groups and analyzed statistically using the paired *t* test. The differences of radiographic parameters between groups P and S also were analyzed using the Student *t* test. The results of these analyses were considered significant when p values were less than .05.

Results

Percent Displacement at Each Rotational Position

The percent displacement of the ulnar head at each rotational position was compared between the injured and uninjured sides.

Restricted supination (group S). On the injured side the average percent displacements of 11 patients in group S at neutral, supination, and pronation were 7% dorsal, 2% dorsal, and 8% dorsal, respectively (Fig. 5). When compared with the uninjured side (3% dorsal, 11% palmar, 7% dorsal, respectively) the ulnar head was located dorsally at maximum supination in the injured side (p = .034), which means that the dorsal translation of the distal radius during forearm neutral to supination was restricted (Fig. 6).

Restricted pronation (group P). In the injured side the average percent displacements of 11 patients in group P at neutral, supination, and pronation were 17% palmar, 17% palmar, and 8% palmar, respectively (Fig. 7). When compared with the uninjured side (0% dorsal, 6% palmar, 4% dorsal, respectively) the ulnar head was located palmarly at all rotational positions on the injured side (Fig. 8) and the difference was significant at neutral rotation (p = .039).

Radiographic Parameters in Each Group

Each radiographic parameter was compared between the groups (Table 1). Palmar tilt and ulnar variance

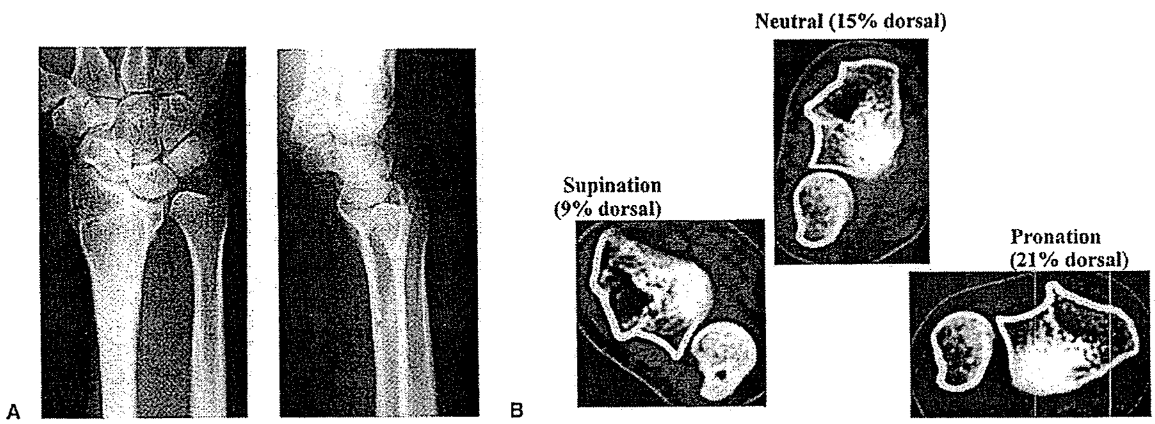


Figure 6. The injured side of the patient with restricted supination. (A) Plain x-ray shows the ulnar-positive variance (4 mm). Palmar tilt and radial inclination are nearly normal. (B) The palmar translation of the ulnar head is restricted in supination.

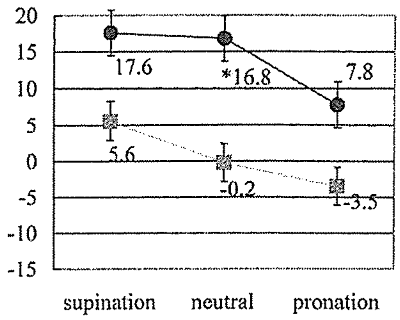


Figure 7. The percent displacement of the ulnar head in group P (restricted pronation). The ulnar head on the injured side was located palmarly at the 3 rotational positions compared with the uninjured side. *$p < .05$, paired *t* test between the injured and the uninjured side. ●, injured; ■, uninjured.

showed significant differences between the groups. Palmar tilt was decreased significantly greater in group P (average, −21°) than in group S (average, −6°) (p = .016). The ulnar variance was more positive in group S (average, +4 mm) than in group P (average, +2 mm) (p = .010). The other radiographic parameters showed no significant differences (radial inclination, p = .080; radial shift, p = .062; dorsal shift, p = .498; pronation–supination deformity, p = .754).

Discussion

Distal radial malunion frequently causes subluxation of the DRUJ, which can be one of the reasons for pain and limited forearm rotation on the ulnar side of the wrist.[1–6] Although several cadaveric studies have reported the effects of malunion on kinematics of the DRUJ and forearm rotation, there have been few systematic *in vivo* analyses that have shown alteration of the congruity of the DRUJ after distal radial malunion.[16–19] This study was designed to investigate the relationship between limited forearm rotation and subluxation of the DRUJ and 6 radiographic parameters including rotational deformity of the distal radius. The most reliable method to evaluate the subluxation of the DRUJ in the clinical situation would be a CT scan. The percent displacement used in this study enabled the estimation of the position of the ulnar head relative to the sigmoid notch of the radius.

Adams[16] investigated the kinematic changes by creating a deformity of the distal radius in fresh specimens and concluded that excessive radial shortening caused the greatest disturbance in kinematics of the DRUJ, whereas decreased radial inclination and dorsal angulation caused only intermediate changes. More recently Moore et al[17] investigated the 3-dimensional kinematic alterations of the DRUJ in pronation–supination after malunited distal radius fractures *in vivo* by using CT imaging. The location and orientation of the rotation axis did not change in the malunited wrists and no dorsopalmar translation at pronation–supination was detected in the study. These investigators attributed the reasons for these findings to adaptation of the soft tissues after malunited distal radius.

It has been acknowledged that the ulnar head is located palmarly relative to the distal radius in supination and dorsally in pronation because of the dorsopalmar translation of the distal radius in the normal wrist, which was recognized on the uninjured side in this study (Figs. 5, 7). On the injured side, however, the dorsopalmar position of the ulnar head at the

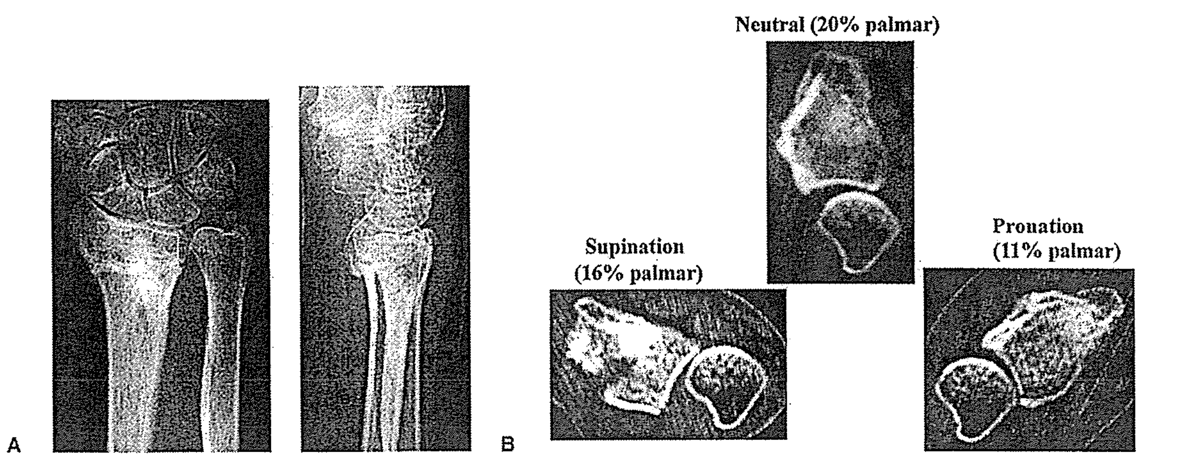


Figure 8. The injured side of the patient with restricted pronation. (A) Plain x-rays show the decreased palmar tilt (−20°). (B) The ulnar head is located palmarly at the 3 rotational positions.

Table 1. Comparison of Each Radiographic Parameter Between the Groups

	PT, degrees*	RI, degrees	UV,* mm	RS, mm	DS, mm	Pro–Supi, degrees
Restricted supination	−6.1 ± 15.2	−2.2 ± 5.4	+3.8 ± 2.0	+1.0 ± 3.1	+2.1 ± 3.0	−5.4 ± 8.7
Restricted pronation	−21.1 ± 12.4	−6.5 ± 5.4	+2.0 ± 1.3	+3.4 ± 1.5	+1.4 ± 1.7	−6.9 ± 9.2

Values are presented as the mean ± SD.

Each parameter was compared between the groups.

PT, palmar tilt; RI, radial inclination; UV, ulnar variance; RS, radial shift; DS, dorsal shift; Pro–Supi, pronation–supination deformity (+, supination; −, pronation).

*$p < .05$.

DRUJ was altered according to the deformity of the distal radius.

The position of the ulnar head showed a significant correlation with limited forearm rotation. In the group with restricted pronation the ulnar head was located palmarly at all rotational positions. By contrast in the group with restricted supination the ulnar head was located dorsally at supination. Kihara et al[18] investigated the effect of a dorsally angulated distal radius on the congruency of the DRUJ by using cadaveric specimens. In their study they concluded that the incongruency of the DRUJ occurred with a change of more than 20° of dorsal angulation of the distal radius and forearm rotation decreased significantly with dorsal angulation by more than 30°. In our study the palmar tilt of the group with restricted pronation was an average −21° compared with the uninjured side. The increased dorsal tilt caused the palmar location of the ulnar head relative to the distal radius. The malposition of the ulnar head might block the palmar translation of the radius in pronation and also elicit changes of the tension of the surrounding soft tissues including the triangular fibrocartilage complex, the capsule of the DRUJ, and the interosseous membrane, which could result in restricted pronation. By contrast the group with restricted supination showed an average ulnar-positive variance of 4 mm compared with the uninjured side. The dorsal translation of the distal radius was reduced in neutral to supination and the ulnar head was located dorsally at supination compared with the uninjured side. The severe ulnar-positive variance might block the dorsal translation of the distal radius during supination, resulting in limited supination.

With regard to the rotational deformity of the malunited distal radius Fernandez[2,3] stated that the distal fragment was flexed and pronated in Smith type fractures with dorsal subluxation of the ulnar head, which resulted in limited forearm supination. In Colles' type fractures the distal fragment was extended and supinated with palmar subluxation of the ulnar head.[2,3] The rotational deformity of the distal radius, however, showed no significant difference between the limited supination and pronation groups in our study. Prommersberger et al[15] evaluated the rotational deformity in malunited distal radius fractures and concluded that loss of pronation–supination did not correlate with the amount of rotational deformity, which is consistent with our results. In our study the number of patients was small and the rotational deformity was less than 15°, which might be why we could not detect exactly the influence of pronation–supination deformity of the distal radius on the restricted rotation. A further study will be needed to determine the effect of the rotational deformity.

From this *in vivo* study we proved the relationship between restricted forearm rotation after a healed distal radius fracture and subluxation of the DRUJ. The radiographic parameters of dorsal tilt of the distal radius and ulnar-positive variance especially showed an adverse influence on the dorsopalmar position of the ulnar head at the DRUJ, which led to limited pronation and supination.

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PALMAR DISLOCATION OF THE METACARPOPHALANGEAL JOINT OF THE FINGER

TSUYOSHI MURASE, HISAO MORITOMO and HIDEKI YOSHIKAWA

From the Department of Orthopaedics, Osaka University Graduate School of Medicine, Suita, Japan

We report a case of palmar dislocation of a finger metacarpophalangeal joint. Disruption of all the supporting structures of this joint and rupture of the flexor tendon sheath caused marked instability. Treatment was by open reduction and repair of the collateral ligaments.

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Keywords: metacarpophalangeal joint, palmar dislocation, surgery

Although dorsal dislocations of the metacarpophalangeal joint are well documented (Green and Terry, 1973; Kaplan, 1957), palmar dislocations of this joint are rare.

CASE REPORT

A 52-year-old woman suffered an injury to her left hand when she was dragged with great force by a dog while holding the dog leash in her left hand. Dorsal dislocations of the proximal interphalangeal joints of the middle and little fingers, and a palmar dislocation of the metacarpophalangeal joint of the ring finger were diagnosed (Fig 1). The proximal interphalangeal joints were successfully reduced under local anaesthesia, but reduction of the metacarpophalangeal joint failed. She was referred to us, 6 days later and an open reduction was attempted. Through a dorsal incision, the extensor hood was incised radial to the extensor tendon. The base of the proximal phalanx was found palmarly dislocated, and the flexor tendon lay radial to the joint (Fig 2). Both of the collateral ligaments were torn, and the dorsal capsule was avulsed from the dorsal aspect of the base of the proximal phalanx. There was a small chondral defect on the dorsoulnar aspect of the metacarpal head. The metacarpophalangeal joint could be reduced manually, but it was unstable, and readily redislocated palmarly. A palmar incision was then made, revealing a rupture of the flexor tendon sheath and avulsion of the palmar plate from the base of the proximal phalanx (Fig 3). The base of the proximal phalanx protruded on the ulnar side of the flexor tendon into the subcutaneous layer. The radial collateral ligament was mainly avulsed from its distal, and the ulnar collateral ligament from its proximal, attachment. Both collateral ligaments were repaired with suture anchors (Micro Anchor, Mitek, Norwood, MA), stabilizing the joint (Fig 4). The extensor hood was repaired and the finger was immobilized with the metacarpophalangeal joint in 30° flexion in a dorsal splint for 2 weeks. Active range of motion exercises were then started. Eight months after surgery the metacarpophalangeal joint flexed to 70° and the extension was only limited by 10°. The patient experienced no pain or disability in any of her daily activities.

DISCUSSION

Palmar dislocation of the metacarpophalangeal joint of a finger is a rare injury. Since the first description by McLaughlin (1965), only 15 cases have been reported in English language literature (Table 1), and its pathogenesis remains uncertain (Hargarten and Hanel, 1992; Lam et al., 2000). Wood and Dobyns (1981) reported three cases, and reproduced the injury in five of ten cadaver specimens by applying hyperflexion and a proximal translational force to the proximal phalanx. They concluded that avulsion of the dorsal capsule from the metacarpal neck and its interposition into the metacarpophalangeal joint as a result of a hyperflexion injury were the essential pathologic processes in the injury. Renshaw and Louis (1973), however, stated that the mechanism of injury is forceful hyperextension of the metacarpophalangeal joint, followed by distal attachment avulsion of the palmar plate which is subsequently entrapped in the palmarly dislocated metacarpophalangeal joint. However, they could not reproduce either disruption of the palmar plate or the palmar dislocation in any of 16 cadaver specimens. Betz et al. (1982) suggested that a combination of active flexion and forceful hyperextension was important in producing a palmar dislocation, and stated that the lack of an active flexion component explained why it had not been possible to produce palmar dislocations in cadavers. Rotatory force was thought to be responsible for the ruptures of the collateral ligaments that occurred in four of the 15 previously reported cases (Betz et al., 1982; Mlsna et al., 1993; Moneim, 1983; Wood and Dobyns, 1981).

From the history obtained from our patient, the main cause of the injury in our case was probably a hyperextension force applied during strong active flexion of the digit. The chondral defect at the dorsoulnar aspect of the metacarpal head and the rupture of the palmar plate also suggest that a

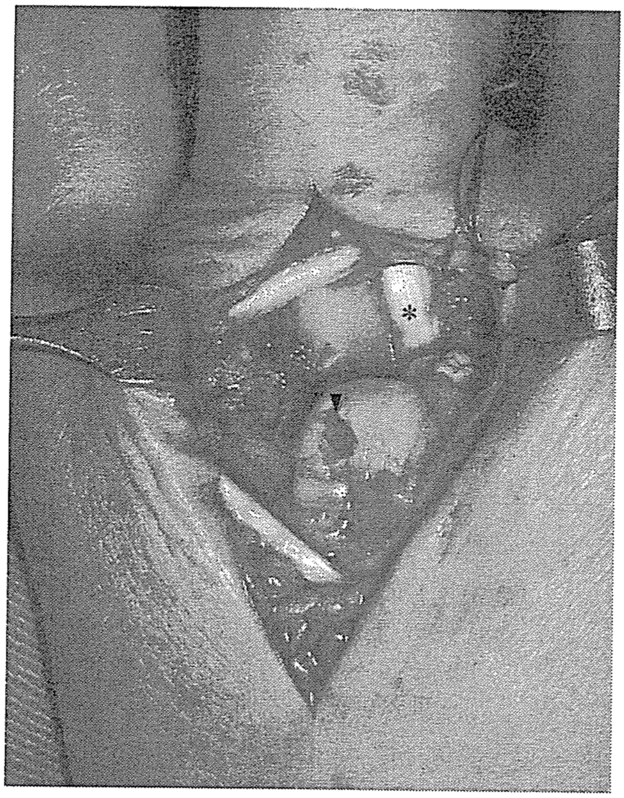

Fig 2 Intraoperative photograph through the dorsal incision. The base of the proximal phalanx is palmarly dislocated, and the flexor tendon (asterisk) lies radial to the metacarpophalangeal joint. There is a small chondral defect at the dorsoulnar aspect of the metacarpal head (arrow head).

hyperextension injury was the mechanism of dislocation. The rupture of the collateral ligaments may indicate that forceful rotation occurred during the dislocation.

Reduction in our case was not difficult, but the joint easily dislocated palmarly until the collateral ligaments were repaired.

The rupture of the flexor tendon sheath as well as the ruptures of the palmar plate and the collateral ligaments may explain the palmar instability. If the tendon sheath is not intact, the flexor tendons run more palmarly than normal when the metacarpophalangeal joint is flexed and this makes their moment arm greater than that of the extensors. In an unstable metacarpophalangeal joint which has no support from the collateral ligaments, the palmar plate or the joint capsule, this imbalance of the flexor–extensor mechanism may make the joint unstable in the palmar direction. This is why maintenance of the reduced position was difficult in our case.

Fig 1 a) Radiograph of the initial injury. Dorsal dislocations of the proximal interphalangeal joints of the middle and little fingers and a palmar dislocation of the metacarpophalangeal joint of the ring finger. b) after reduction of proximal interphalangeal joints.

In cases where the metacarpophalangeal joint is stable after closed reduction, non-operative treatment yields the favourable functional results (Boland, 1984; Khuri

Fig 3 Intraoperative photograph through the palmar incision. The sheath of the flexor tendon (asterisk) is ruptured and the palmar plate is avulsed from the base of the proximal phalanx (arrow head). The collateral ligaments (small arrows) still attached to the base of the phalanx are also torn.

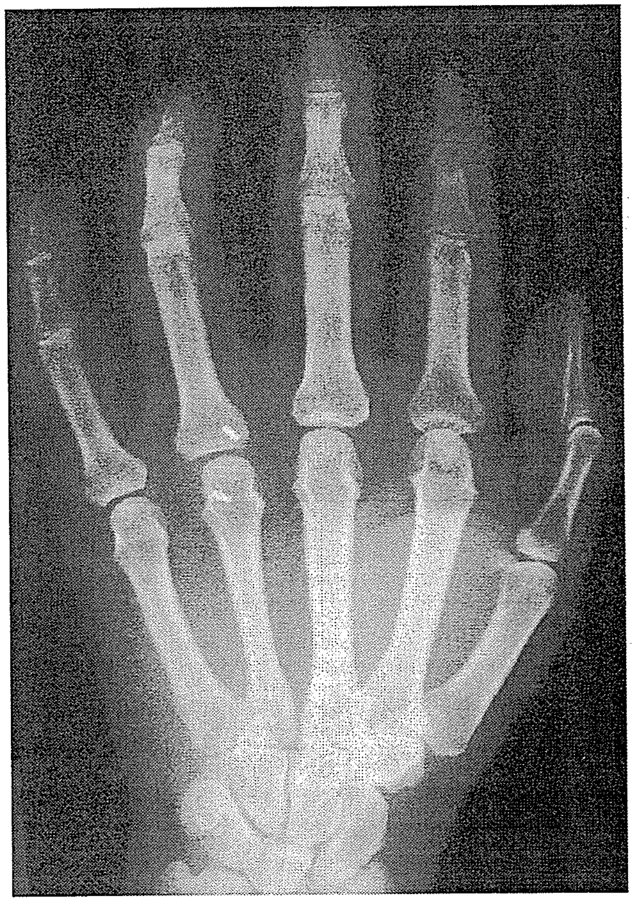

Fig 4 Both of the collateral ligaments were repaired using suture anchors.

Table 1——Reported cases

First author	*Age (years)*	*Sex*	*Injured side*	*Injured finger*	*Mechanism of injury*	*Surgery*	*Time from injury to surgery*	*Surgical procedure*	*Articular interposition*	*Final flex/ext arc (degrees)**
McLaughlin (1965)	—	—	—	Middle	—	Yes	—	OR	DC	—
Renshaw (1973)	48	M	L	Little	H.E.	Yes	2 weeks	OR	PP	60
Wood (1981)	17	F	L	Index	H. F.	Yes	9 months	Arthrodesis	DC	0
	20	M	R	Middle	H. F.	Yes	2 weeks	OR+TF	DC	—
	61	F	R	Middle	H. F.	Yes	5 months	Arthroplasty	DC	60
Betz (1982)	70	F	L	Ring	H.E.	Yes	—	OR+repair of UCL, PP	PP, UCL	Full
Moneim (1983)	59	M	R	Little	H. F.	Yes	7 weeks	OR+repair of RCL, UCL, PP, DC+ TF	PP	70
Boland (1984)	65	F	L	Ring	H. F.	No	0	—	—	Decreased by 20
Khuri (1986)	31	M	L	Ring	H. F.	No	0	—	—	Full
Hargarten (1992)	66	M	R	Little	H. F.	Yes	4 weeks	OR	—	65
Qui (1992)	20	M	R	Index	H. F.	Yes	3 weeks	OR+TF	PP	20
Mlsna (1993)	68	M	R	Little		Yes	3 weeks	OR+repair of RCL	DC	65
Takami (1999)	20	M	R	Ring	—	No	0	—	—	Full
	60	F	R	Ring	—	No	0	—	—	75
Lam (2000)	44	M	L	Ring	H. F.	Yes	0	OR+TF	PP	80
Present study	52	F	L	Ring	H. E.	Yes	6 days	OR+repair of RCL, UCL	PP	60

Injured side: R, right. L, left. Mechanism of injury: H.E., hyperextension; H. F., hyperflexion. Surgical procedure: OR, open reduction; TF, provisional transfixation with a Kirschner wire. RCL, radial collateral ligament; UCL, ulnar collateral ligament; PP, palmar plate; DC, dorsal capsule; —, not described.

and Fay, 1986; Takami et al., 1999). However, if the instability persists after closed reduction or reduction is impossible, one should not hesitate to carry out an open reduction. Wood and Dobyns (1981) reported a case whose metacarpophalangeal joint redislocated two times after closed reduction, and underwent an arthrodesis 9 months after the initial injury. The results of operative treatment more than 3 months after the injury are generally poor (Qui, 1992; Wood and Dobyns, 1981).

At surgery, if the capsule or the palmar plate are interposed in the metacarpophalangeal joint they should be extracted and the collateral ligaments should be repaired if they are torn. The suture anchor system was useful in our case for repair of the collateral ligaments.

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Dr Tsuyoshi Murase, M.D., Department of Orthopaedic Surgery, Osaka University Graduate School of Medicine, 2-2, Yamada-oka, Suita, Osaka 565-0871, Japan. Tel.: +81-6-6879-3552; Fax: +81-6-6879-3559; E-mail: murase-t@umin.ac.jp

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