Stability of femoral neck fracture

Roentgen stereophotogrammetry of 29 hook-pinned fractures

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The stability of hook-pin fixation during weight bearing was studied in 29 femoral neck fractures using roentgen stereophotogrammetric analysis. Twenty-three fractures became stable within 1 to 9 months, whereas redisplacement or continuing movement of the fracture occurred in 6 cases. Displaced fractures shortened about 7 mm more than undisplaced ones before healing. The rotations of the femoral heads were greatest in the forward/backward direction, followed by varus-valgus tilting in both fracture groups. Rotation about the longitudinal axis was recorded in the displaced fractures, mainly as a retroversion, whereas no rotation occurred about this axis in the undisplaced fractures. Healing after 6 months, intermediate fracture fragments, and a decreased Pauwels' angle seemed to imply increased fracture compression or rotatory instability. Fractures that subsequently developed healing complications displayed an increased distal displacement of the femoral head during the first postoperative month.

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A great number of pins, nails, and screws have been designed to stabilize femoral neck fractures, but their efficiency in vivo has not been established because of a lack of appropriate methods. The results of in vitro studies of fractures, where either static or dynamic loadings are applied, may not always be applicable to the clinical situation due to difficulties in reproducing the fracture and the natural course of weight bearing. By using roentgen stereophotogrammetric analysis (RSA, Selvik 1974, 1989), we have previously reported the three-dimensional fracture movements before weight bearing after hook-pin fixation (Ragnarsson et al. 1989). In the present study, we recorded the fracture movements during weight bearing and until healing, redisplacement, or pseudarthrosis.

Patients and methods (Table 1)

Twenty women and 9 men with a median age of 71 (37–85) years and with fresh femoral neck fractures were included. Before the fracture, all the patients were physically active and ambulatory without walking aids. For inclusion in the study, informed consent was required. Seven fractures were undisplaced Garden (1961) Stages I–II and 22 were displaced Stages III–IV. All the patients were operated on within 1 day of admission. Preoperatively, the displaced fractures were treated with traction. Closed reduction of the displaced fractures was performed during the operation. All the operations were done under spinal anaesthesia. Two Hansson (1982) hook-pins were used to stabilize the fractures.

Peroperatively, 0.8-mm tantalum markers were inserted into the femoral head and the trochanters using 5- or 14-cm cannulas. The cannulas were introduced into the femoral head and the lesser trochanter through the drilling channels before the introduction of the nails. Further markers were inserted percutaneously into the greater trochanter and the femoral head. We aimed at placing a total of four to six markers on each side of the fracture.

The RSA examinations were performed using a uniplanar technique (Selvik 1974, 1989, Kärrholm 1989). A minimum of three stable noncolinear markers are necessary to evaluate femoral head rotations. In most patients, more than three markers in each segment were available. In 1 patient only two stable markers (one distal-medial and one proximal-lateral) could be visualized throughout the examinations excluding the calculation of rotations.

Translations of the femoral head were measured at its center. The center of the femoral head was plotted on the first postoperative stereoradiographs. The two-dimensional position of this point and the bone markers were measured to calculate their

Table 1. Stereophotogrammetry and scintimetry in 29 femoral neck fractures

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	M	37	I	64	–	4.1	0	6	32	–0.6	–0.9	–1.1	1.5	NS	NS	–1.4	1.8
2	F	71	I	62	–	2.4	0	3	26	NS	–2.9	NS	2.9	–3.0	NS	–1.9	4.2
3	F	71	I	48	–	0.7	0	3	25	–0.6	–0.7	NS	0.9	4.0	NS	1.0	4.9
4	F	65	I	48	–	2.4	0	1	25	NS	–0.6	NS	0.6	NS	NS	NS	NS
5	F	62	II	54	–	2.5	0	1	25	–0.7	–2.2	–2.2	3.2	–5.1	NS	NS	6.4
6	M	79	II	48	–	1.4	0	6	12	–2.5	–4.8	–1.8	5.7	NS	NS	–1.7	1.8
7	M	76	II	52	–	np	0	3	9	–1.0	–4.5	–1.5	4.8	–2.8	NS	–1.5	4.0
8	F	69	III	60	+	1.5	0	6	30	–3.5	–4.9	1.4	6.2	–4.4	NS	–9.8	11.5
9	F	62	III	52	–	3.6	0	3	25	NS	–3.2	–1.8	3.7	–5.4	5.8	2.2	8.1
10	M	65	III	36	+	–	2	9	23	–4.0	–12.3	–6.1	14.3	NS	11.2	–11.9	15.8
11	F	77	III	60	–	1.3	0	3	26	–2.4[b]	–9.0[b]	–2.7[b]	9.7	c	c	c	c
12	M	71	III	56	+	2.6	0	6	14	–4.2	–15.2	–2.4	16.0	7.0	2.8	–3.6	8.3
13	F	56	III	70	–	1.4	0	6	25	–1.1	–3.8	–1.3	4.2	–3.3	2.0	1.6	4.6
14	F	66	III	48	–	1.3	0	6	24	–3.8	–10.3	–2.8	11.3	3.0	3.7	–1.4	4.9
15	F	82	III	51	+	0.7	0	6	12	–3.0	–8.3	–4.0	9.7	–4.9	2.9	–5.8	7.9
16	F	81	IV	54	–	1.6	0	1	24	–2.5	–7.6	–1.4	8.1	NS	NS	–1.9	2.2
17	F	79	IV	44	–	0.7	0	3	12	–2.2	–6.3	–3.5	7.5	–8.2	2.2	–3.7	9.5
18	F	72	IV	56	–	2.2	0	6	24	–4.4	–8.2	–3.4	9.9	–1.2	7.0	5.0	5.4
19	M	80	IV	38	+	+	0	9	26	–3.4	–13.0	–7.2	15.2	5.7	5.9	–6.1	8.6
20	F	64	IV	56	–	0.9	0	6	26	–2.1	–8.0	–1.2	8.4	2.3	–2.3	–6.7	10.9
21	F	59	IV	64	–	1.2	2	9	20	–1.2	–7.7	2.1	8.1	13.9	7.6	1.1	15.1
22	M	84	IV	42	–	0.9	0	3	12	–2.4	–9.7	–3.8	10.7	–3.9	7.5	–2.4	5.1
23	F	68	IV	42	–	1.5	0	9	12	–7.5	–9.3	–2.3	12.2	10.0	6.2	–14.8	17.9
24	M	71	III	46	+	0.7	1	a	30	–7.2	–18.8	–8.1	21.7	2.1	–8.2	1.1	7.9
25	M	85	III	68	+	1.0	1	a	12	–7.7	–18.5	–1.8	20.1	1.7	NS	–18.5	21.5
26	F	76	III	67	–	1.2	3	a	3	–2.2	–11.2	–3.7	12.0	8.6	–8.2	–0.7	11.2
27	F	83	IV	49	–	0.8	3	a	1	–2.4	–5.7	NS	6.1	NS	NS	NS	NS
28	F	61	IV	40	–	0.7	3	a	1	–5.0	–16.5	–3.6	17.6	–5.9	–7.7	–5.2	10.8
29	F	78	IV	36	+	1.6	3	a	3	9.4	–16.0	–3.8	18.9	–25.6	–22.4	–29.0	41.3

A Case
B Sex
C Age
D Garden Type (1961)
E Pauwels' angle (1935)
F Intermediate fracture fragment
G Scintimetry (femoral head ratio)
 np not performed
 – reduced uptake, + increased uptake
H Results—plain radiographs
 0 healed
 1 pseudarthrosis
 2 necrosis
 3 redisplacement
I Months between fracture and arrest of femoral head movements
 a did not stabilize

J Months between the fracture and the last follow-up (RSA and plain radiographs)

Translations of the center of the femoral head to arrest (healing)
K + medial, – lateral
L + proximal, – distal
M + anterior, – posterior
N Total (vectorial sum transverse, longitudinal and sagittal K–M)
 NS not significant
 b mean value of two stable tantalum balls

Rotation of femoral head to arrest (healing)
O + forward, – backward
P + retroversion, – anteversion
Q + valgus, – varus
R screw axis rotations
 NS not significant
 c could not be evaluated

three-dimensional position in the laboratory coordinate system. The position of the center of the femoral head could be identified at the subsequent examinations by using the known positions of the femoral head markers at each examination. By this procedure, the influence of changes of the gravitational center of the markers due to occasionally loose or hidden tantalum markers and asymmetric positioning could be minimized (Kärrholm 1989).

The translations of the center of the femoral head were measured in relation to the cardinal axes (medial-lateral, proximal-distal, and anterior-posterior translations); and the vectorial sum of these movements (total translations) were recorded. Femoral head rotations were also measured in relation to these axes (forward-backward, retro-anteversion, and valgus-varus rotations). Rigid-body motion can also be represented as rotations and translations about one axis with a variable orientation called the screw axis (Selvik 1974). In this study, femoral head rotations about this screw axis represented the total rotations.

The first stereophotogrammetric examination was performed on the day after the operation and before the patient was mobilized. Unrestricted weight bearing was then allowed, and subsequent examinations were made after 1 week, 1 month, 3 months, and thereafter at intervals of 3 months. The reproducibility of the calculations has been determined previously (Ragnarsson et al. 1989). When the recorded movements were smaller than the 95 percent significance limit, the fracture was regarded as stable. Repeated examinations were also performed after stabilization to confirm fracture healing by absence of movements during periods of 3 months to 2 years (Table 1).

The preoperative and the first postoperative radiographs were scrutinized concerning the presence of intermediate fracture fragments. The slope of the fracture line according to Pauwels (1935) was measured on the first postoperative radiograph, and before the patient was mobilized.

^{99m}Tc-MDP scintimetry was used to record the vitality of the femoral head in 28 patients (Strömqvist 1983).

The Mann-Whitney *U*-test and the Spearman rank-correlation were used to evaluate the results. *P*-values equal to or lower than 0.05 were regarded as significant.

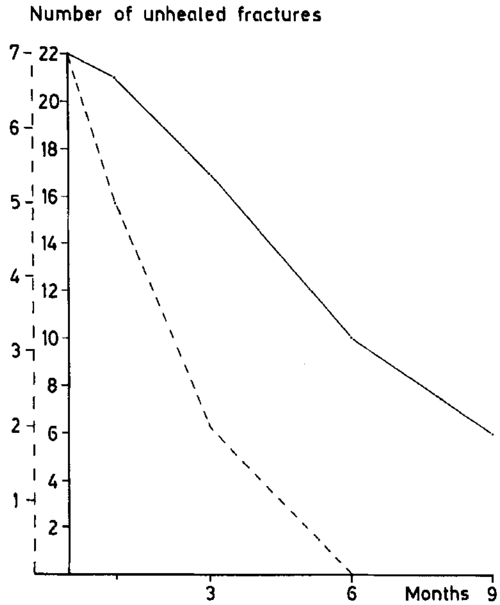


Figure 1. The healing of 29 femoral neck fractures. Displaced fractures are illustrated by an unbroken line and undisplaced fractures by a broken line.

Results

In both undisplaced and displaced fractures, the greatest movements occurred during the first postoperative month. Varying time intervals elapsed before stabilization (Table 1). Six displaced fractures did not heal (Figure 1). The magnitude of the recorded movements 1 month after fracture did not correlate with the results of the isotope studies.

Healed fractures

Translations (Figure 2). Both undisplaced and displaced fractures exhibited the greatest movements in the distal direction followed by lateral translation in the displaced and posterior translation in the undisplaced fractures. The mean shortening in the undisplaced fractures was 2.8 (0.6–5.7) mm versus 9.7 (3.7–16.0) mm in the displaced fractures ($P = 0.001$). Type III fractures displayed almost the same mean fracture compression (total translation) as did the Type IV fractures: 9.4 (3.7–16) mm and 10 (7.5–15) mm, respectively. The number of undisplaced fractures was too small for a corresponding evaluation. The time period between fracture and stabilization did not influence the size of the fracture movements.

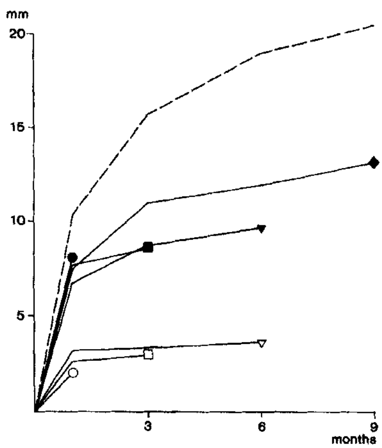
Rotations (Figure 3). In both groups the mean absolute rotations were greatest about the transverse axis (undisplaced 3.8°, displaced 5.6°) followed by rotation about the sagittal axis (1.5° and 5.2°). No rotations occurred about the longitudinal axis in the undisplaced fractures, whereas the mean absolute rotation of the displaced fractures was 4.7°. The rotatory movements in Garden Type III fractures did not differ from those recorded in Type IV fractures.

The rotations about the transverse axis were the least predictable and did not differ when comparing displaced with undisplaced fractures, whereas rotations about the other two axes mainly occurred in the same direction and were greater in the displaced fractures ($P < 0.01$). Hence, varus angulation was observed in four of five undisplaced and in 11 of 15 displaced fractures.

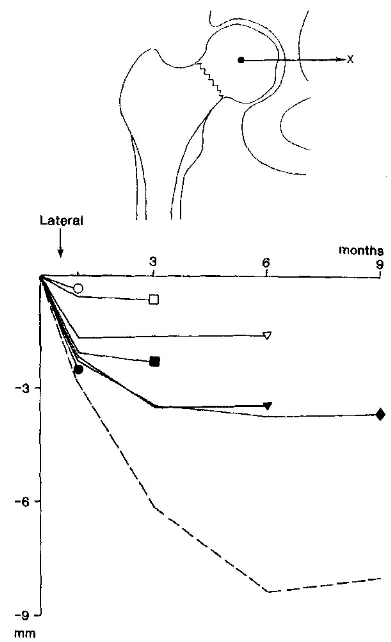
Retroversion was recorded in nine of 11 displaced fractures. Two fractures (Cases 10 and 21) that subsequently developed femoral head necrosis (confirmed radiographically at 20 and 22 months postfracture) disclosed pronounced rotation (screw axis rotations 16° and 15°). In these two fractures, movements did not cease until 9 months postoperatively. An increased time period between the fracture and stabilization seemed to imply increased screw axis rotation (fractures stabilized at 3–6 versus 9 months; $P = 0.05$).

Unhealed fractures

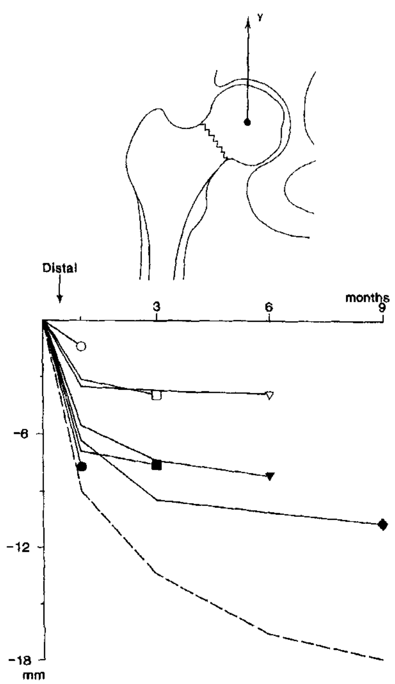
Translations (Figure 2). Fractures that did not heal displaced about 4 mm more distally during the first



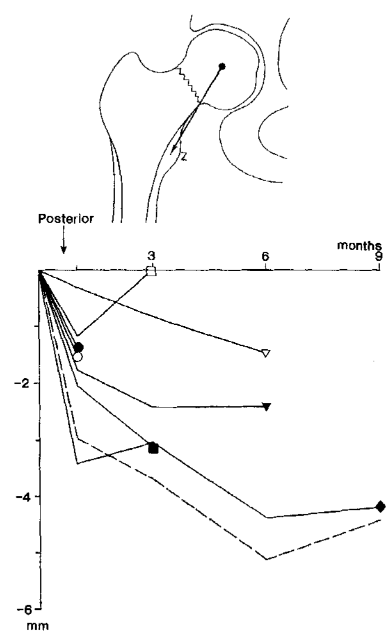
A. Total translations.



B. Translation along the transverse (X) axis.

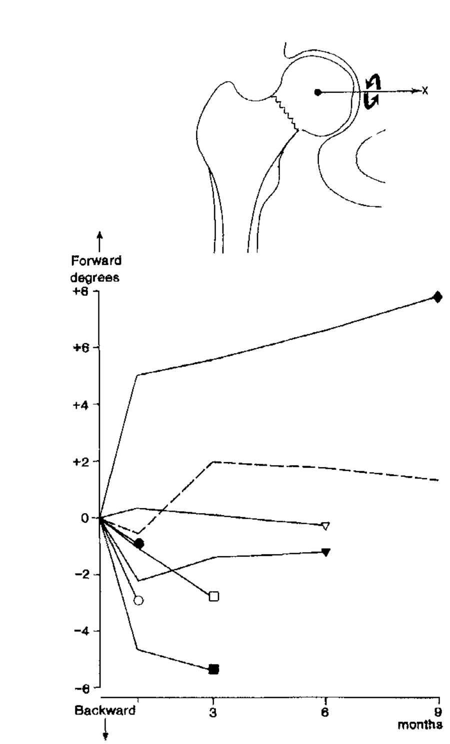


C. Translation along the longitudinal (Y) axis.

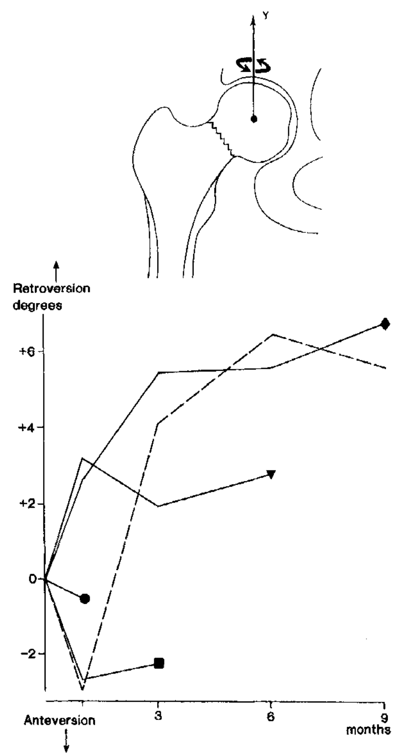


D. Translation along the sagittal (Z) axis.

Figure 2. Translations of the femoral head (median values) in 23 femoral neck fractures stabilizing at different times postoperatively. ○, □, ▽, and ◇ undisplaced fractures (full signs—displaced fractures) stabilized at 1, 3, 6, and 9 months, respectively. An additional six fractures did not stabilize (broken line).

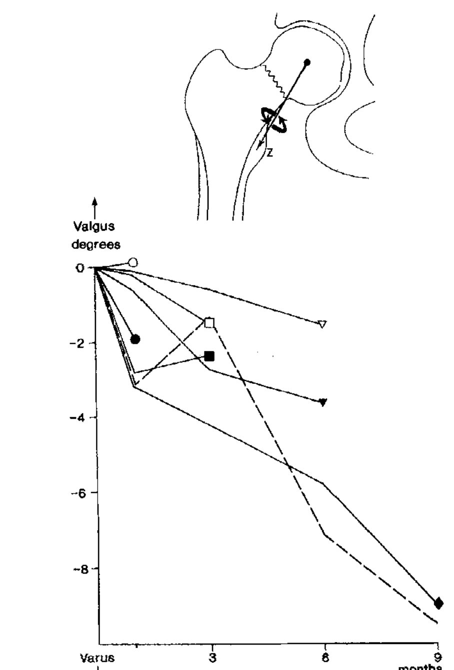


A. Rotation about the transverse axis.



B. Rotation about the longitudinal axis.

Figure 3. Rotational movements (median values) in 28 patients with femoral neck fractures from the first postoperative day. (The rotational movements in Case 11 could not be evaluated). Symbols according to Figure 2.



C. Rotation about the sagittal axis.

postoperative month than fractures that subsequently healed with a mean distal displacement of 10.3 (5.7–17) mm versus 6.0 (2.0–8.6) mm; $P = 0.04$. This difference increased with increased weight-bearing time. No differences in lateral or posterior displacements were noted.

Rotations (Figure 3). The femoral head rotations did not differ between healed and unhealed fractures when we compared the values in the healed fractures at the time of stabilization with the last recorded values in the unhealed fractures. Anteversion was more commonly recorded in fractures with early redisplacement.

Fracture anatomy

Intermediate fracture fragments were visible in eight displaced fractures with a mean shortening of 6 mm more than in displaced fractures without intermediate fragments ($P = 0.05$). An increased Pauwel angle implied a slight tendency to reduced fracture compression (total translation) when evaluated in all the healed displaced fractures (Spearman's coefficient of correlation –0.55, $P = 0.03$). When evaluated in all the displaced fractures, the highest correlation was noted between Pauwels' angle and posterior translation (Spearman's coefficient of correlation – 0.6, $P < 0.001$).

Discussion

Postoperative displacement of femoral neck fractures has been evaluated indirectly as extrusion or telescoping of the fixation device (Charnley et al. 1957, Rydell 1964, Fielding 1981), or by using anatomic landmarks on conventional radiographs (Edholm and Thorling 1981). According to Charnley et al. (1957), continuing extrusion of nails could occur up to 9 months, the greatest shortening being 7.5 mm. Rydell (1964) measured fracture compression between 5 and 10 mm, which generally was most pronounced during the early postoperative period. Fielding (1980) measured the amount of telescoping on radiographs in displaced fractures treated with one of the many hip compression screw systems available. The average fracture compression was 11 mm, most of it occurring during the first 4 weeks. Progressive shortening for periods longer than 4 weeks was associated with healing complications in all the cases. Edholm and Thorling (1981) calculated femoral shortening after stabilizing intracapsular hip fractures with the Deyerle device, and stated that marked shortening 3 months postoperatively should be interpreted as an indication of nonunion.

The shortening in our displaced fractures varied from 4 to 16 mm and continued in about two thirds of the cases up to 6–9 months. Small signs of fracture movements may occur in spite of the fracture being considered healed on ordinary radiographs (Charnley et al. 1957). In agreement, the movements after 1 month in our study were rather small, and could probably not be measured on conventional radiographs. Most of our fractures were healed after 6 months; a potential for osseous union seemed to exist until at least 9 months after fracture. We believe that the absence of micromovements is a more adequate definition of union than clinical and radiographic signs.

Baril et al. (1975) stated that the importance of rotatory stability in femoral neck fractures is not known. Nevertheless, many implant designs have focused on the neutralization of rotatory forces (Smith-Petersen et al. 1931, Rydell 1961, Laing and O'Donnell 1961). Multiple pins/screws have been advocated to provide the best possible torsional control (Deyerle 1959, Kofoed and Alberts 1980). However, the rotatory movements after internal fixation of femoral neck fractures have not previously been measured until healing.

In our study the rotatory movements of the undisplaced fractures were rather small, but still present in both Stages I and II fractures. Immediately after the operation, the muscles and gravity may influence the position of the fracture fragments (Ragnarsson et al. 1989). During weight bearing, postero-distally directed forces may become dominant (Wroblewski 1979). Consequently, we recorded distal displacement of the femoral head in both displaced and undisplaced fractures. The posterior displacement was also comparatively pronounced in undisplaced fractures, whereas the displaced ones also displayed retroversion, perhaps as an effect of posterior fracture comminution, which was radiographically verified in eight of the fractures.

The negative correlation between the slope of the fracture line and the shortening of the femoral neck in the displaced fractures that healed may reflect that an increased area of contact between the fracture fragments is advantageous for healing provided the osteosynthesis is stable. Visible intermediate fracture fragments were associated with increased instability, an observation noted earlier (Garden 1961, Frangakis 1966, Scheck 1980).

Three fractures had pronounced rotational movements before healing. Two of them developed femoral head necrosis during the observation period. One of these cases had an unfavorable scintimetric result, and was thus expected to develop healing complications, whereas the other had a favorable uptake ratio. Perhaps rotatory malposition about the transverse axis might have twisted the ligament of the femoral head and caused obliteration of its vessels and ischemic necrosis, as postulated by Frangakis (1966).

In conclusion, more or less pronounced compression and rotatory displacements in the early postoperative period were followed by micromovements in femoral neck fractures that subsequently healed, in most cases continuing up to 6 months, and in a few cases up to 9 months, after the fracture. After 1 month of weight bearing, the greatest distal displacements were recorded in the fractures that subsequently did not heal.

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