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ABSTRACT

Introduction: The aim of this study was to determine the degree of ROM limitations of extremities, joints and planes of motion after burns and its prevalence over time.
Method: The database of a longitudinal multicenter cohort study in the Netherlands (2011–2012) was used. From patients with acute burns involving the neck, shoulder, elbow, wrist, hip, knee and ankle joints that had surgery, ROM of 17 planes of motion was assessed by goniometry at 3, 6 weeks, 3–6–9 and 12 months after burns and at discharge.
Results: At 12 months after injury, 12 out of 17 planes of motion demonstrated persistent joint limitations. The five unlimited planes of motion were all of the lower extremity. The most severely limited joints at 12 months were the neck, ankle, wrist and shoulder. The lower extremity was more severely limited in the early phase of recovery whereas at 12 months the upper extremity was more severely limited.

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Conclusion: The degree of ROM limitations and prevalence varied over time between extremities, joints and planes of motion. This study showed which joints and planes of motion should be watched specifically concerning the development of scar contracture.

1. Introduction

After burn injuries, range of motion (ROM) limitation of joints is a common complication, seen from the moment of admission to the hospital till years after the accident [1–3]. In the acute phase, edema, pain, fear, post-surgical effects, starting wound contraction and mental- and physical weakness, may cause ROM limitation. At a later stage, ROM limitation is increasingly the result of scar contraction and finally of scar contracture [4–10].

Initially basic daily activities like, feeding, dressing, hygienic self-care, toileting and mobilization may be restricted to a greater or lesser extent. At a later stage during recovery, ROM limitations may have serious impact on quality of life, participation in social life and return back to work [11–13].

Although joint limitations after burn injuries are considered a serious complication in burn care, published information about the prevalence and severity of joint ROM limitations is still sparse. Studies that are available, mostly limit themselves to analyzing post burn joint limitation during hospitalization or at discharge from the hospital [3–5,14,15]. Long term follow- up studies beyond this period are lacking. However, because of the maturation process of a burn scar in the long term, the pliability, extensibility and length of the scar will change overtime [16,17], thereby it might be expected that as a result the ROM limitations of the affected joints will change over time too. This was confirmed by the study of Schouten et al. [8], one of few longitudinal studies, that showed that concerning the prevalence of ROM limitations of all joints grouped together, 58% of the joints were limited at discharge, declining till 21% at 12 months. These findings emphasize the importance of long-term ROM follow up studies, in order to be able to understand and potentially predict the course of ROM limitations after burn injuries for as well the prevalence as the degree of ROM limitation.

Whereas the prevalence of ROM limitations provides valuable information to compare patient populations, joints, planes of motion and to predict ROM limitations in the long term, it is unclear to what extent the ROM of the particular joints are limited in terms of severity. Which are important markers to follow a patient's progress, to qualify ROM limitations in measures of severity, and to guide treatment interventions [18].

Therefore, the aim of this study was to determine the degree of ROM limitation of extremities, joints and planes of motion after burn injury and its prevalence over time.

This info will guide the burn team and patients in their daily practice.

2. Patients and methods

To identify the degree of joint ROM limitation after burn injury over time, measurement data were extracted from the database of a prospective multicentre cohort study conducted by the burns centres of the Martini hospital in Groningen and the Red Cross hospital in Beverwijk, both in The Netherlands [8]. In 2011 and 2012, for a period of 12 months, patients admitted to one of these burn centres were recruited to this study. Consecutive patients with acute burns across or adjacent to the neck, shoulder, elbow, wrist, hip, knee and

Table 1 – ROM severity classification ratings (in degrees).

Joint	Plane of motion	Normative ROM	Minor	Mild	Moderate	Severe
Neck	Extension	45	<11	11–22	23–34	>34
	Lateral flexion	45	<11	11–22	23–34	>34
	Rotation	60	<15	15–30	31–45	>45
Shoulder	Flexion	180	<45	45–90	91–135	>135
	Abduction	180	<45	45–90	91–135	>135
Elbow	Flexion	150	<38	38–75	76–113	>113
	Extension	−150	<−38	−38 to 75	−76 to 113	>−113
	Supination	80	<21	21–40	41–60	>60
Wrist	Palmar flexion	80	<21	21–40	41–60	>60
	Dorsal flexion	70	<18	18–35	36–53	>53
Hip	Flexion	120	<30	30–60	61–90	>90
	Extension	20	<5	5–10	11–15	>15
	Abduction	40	<10	10–20	21–30	>30
Knee	Flexion	135	<34	34–67	68–102	>102
	Extension	−135	<−34	−34 to 67	−68 to 102	>−102
Ankle	Dorsal flexion	20	<5	5–10	11–15	>15
	Plantar flexion	50	<13	13–25	26–38	>37

ankle were eligible. For these joints, seventeen planes of motion that were regarded as most at risk for ROM limitation by burn scar contracture were included.

Because the study of Schouten et al. demonstrated that non-operated joints recovered without ROM limitations, in this study only the operated joints were analyzed.

Exclusion criteria were pre-existing pathology interfering with joint ROM, hospitalization for less than 2 days, or having died within 4 weeks after the burn injury. The Dutch Burn Repository R3 was used to extract characteristics of patients and burns. Ethical approval was obtained from the Institutional Ethics committee of the Martini hospital (no. 2011-19).

ROM was measured passively at week three and subsequently every three weeks until discharge, and at 3, 6, 9 and 12 months. Furthermore, the time point of discharge from the hospital was added to the measurement data, to enable comparison to other data in the literature. This discharge time point is presented separately at the end of the timeline, because the moment of discharge varied considerably between patients and does not fit at a specific time point in the timeline. ROM was measured passively with a Baseline TM 12.5-inch, 3608 transparent plastic goniometer according to the standardized protocols of Norkin and White [19]. To control for difference in normal ROM values of the various joints, limited ROM data were indexed to percentages of normal ROM values, rather than absolute ROM values. The normal ROM values were those of the American Association for Orthopedics Surgery (AAOS).

Taking into consideration the minimum detectable change, planes of motions were considered limited if the ROM was $>9^{\circ}$ short of normal ROM, except those concerning the ankle, for which $>5^{\circ}$ was used [20]. Joints were considered impaired if at least one plane of motion was limited. Furthermore, the limited ROM data were classified in terms of degree of limitation. To this end, the normal ROM of the particular planes of motion was divided in quarters: $\leq$25% limited ROM was classified as minor, 26–50% limited ROM as mild, 51–75% limited ROM as moderate and $\geq$76% limited ROM as severe limitation (Table 1). This classification system was decided on for this study, because a generally accepted classification system in burn care is lacking. Commonly, an arithmetical subdivision of the full ROM is used, e.g Schneider et al. divided in thirds [4], Huang et al. in halves [21]. To increase detail, we divided in fourths and also included the unlimited planes of motion.

Time points of measurements were during hospitalization in week three and subsequently every three weeks until discharge, at discharge and during follow-up at the outpatient clinic every three months, until 12 months post burn.

The ROM measurement result at discharge is presented separately at the end of the timeline, because the moment of discharge varied considerably between patients and does not fit at a specific time point in the timeline.

During admission in the burn center, patients received a daily rehabilitation program adapted to the physical and mental capabilities of the individual patients. Exercises to prevent or restore ROM limitations were preferably performed actively. However, patients that were unable to fulfill an active ROM program because of physical and mental weakness were supported with active assisted- or passive exercises. Passive stretching exercises to restore ROM limitations was not an integral part of our rehabilitation approach, because we are not convinced of the positive effects of mechanical tension on the prevention or elongation of healing scar tissue [22]. According to this approach, also splinting therapy to prevent or restore ROM limitations as a result of contracted scars was applied with restraint. The rehabilitation program further existed of muscle strengthening, cardio-pulmonary reconditioning and ADL training. After discharge from the burn center, patients were further treated in by their local physiotherapist or, in a few cases in rehabilitation centers as in- or outpatient, depending on the physical and mental state of recovery.

2.1. *Data analyses*

Descriptive analysis of data was performed. For an overall impression of the impact of post burn joint limitation during recovery, all limited planes of motion were grouped together and analyzed. Subsequently, data were analyzed per joint plane of motion. Data were analysed using IBM SPSS 20 (Version 20.0. Armonk, NY: IBM Corp.).

3. Results

Included for analysis were 117 patients and 353 joints that were operated. The number of operated joints measured at each specific time point during recovery is presented in Table 2. Patient- and burn characteristics are presented in Table 3.

Table 2 – Number of operated joints measured at specific time points during recovery (wk: weeks, mo: months).

Joint	N=	3 wk[a]	6 wk[a]	3 mo[a]	6 mo[a]	9 mo[a]	12 mo[a]	Discharge
Neck	19	17	16	16	14	15	13	17
Shoulder	62	58	55	52	56	53	48	58
Elbow	82	69	66	78	74	68	60	76
Wrist	82	76	82	75	68	58	59	78
Hip	35	28	24	27	26	21	18	29
Knee	53	51	47	48	42	34	27	49
Ankle	20	17	18	18	19	14	14	18
	353	316	308	314	299	263	239	325

[a] Time point after burn injury.

Table 3 – Patient- and burn characteristics of the operated burned joints.

	Operated burns
N = subjects	117
N = joints	353
Sex. N = male (percentage)	73 (63%)
Age (mean, SD)	42.2 (24.4)
Age (range)	0–90
TBSA (mean, SD)	14,0 (15.6)
TBSA (range)	0,50–92%
LOS (mean, SD)	28,7 (17.9)
LOS (range)	2–108
Burns aetiology:	
- Flame	46 (39.2)
- Hot fluid	29 (24.8)
- Flash-burn	25 (21.4)
- Chemical	5 (4.3)
- Other	12 (10.3)

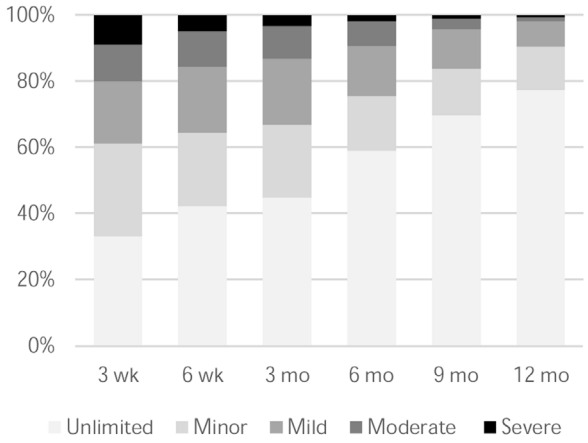

Fig. 2 – Percentage of joints limitation per severity classification over time (wk: weeks, mo: months).

3.1. *ROM limitations of all 17 planes of motion grouped together*

At three weeks post burn the mean limited ROM of all planes of motion grouped together was 37% (SD 21). This remained steady till 3–6 months and then gradually declined to 17% (SD 15) at 12 months (Fig. 1). At 3 weeks post burn 33% (SD 15.9) of all planes of motion were unlimited. For the remaining 67% limited planes of motion, 28% (SD 14.7%) had minor limitations, 19% (SD 12.0) had mild limitations, 11% (SD 9.6) had moderate and 9% (SD 14.6) severe limitations. At 12 months 77% (SD 18.6) of all planes of motion were unlimited and for the remaining 23% limited planes of motion, most of the planes of motion were classified minor or mild (14% and 8% respectively) and just 1% of the limited planes of motion were classified moderate and 1% severe (Fig. 2).

3.2. *Limitation of ROM per joint plane of motion*

In Table 4 and Fig. 3, the mean limited ROM as a percentage of the full ROM and standard deviation of the 17 measured planes of motion at the consecutive time points are presented.

Analyzing the particular planes of motion of the neck showed that extension was the most limited plane of motion during the whole period of follow-up (Fig. 3, Table 4). ROM of abduction and ante-flexion of the shoulder were almost equally limited during the entire study period. The shoulder abduction was most limited at three months post burn (42%. SD 18). The ante-flexion was most limited at 6 months (38%. SD 18). The most limited plane of motion of the elbow was the supination during the entire study period. Most limitations were seen at 6 months for all planes of motion. For the wrist, dorsal flexion was the most limited plane of motion during the entire study period. Most limitations were seen at 3 months (Table 4). For the hip the most limited plane of motion was extension. Most limitations of all planes of motion were seen at 3 weeks, gradually declining till 0% at 12 months post burn. Flexion was already unlimited at 9 months. For the knee, flexion was the most limited plane of motion during recovery. Most limitations, of both flexion and extension were seen between 3- and 6 weeks post burn. Dorsal flexion of the ankle was the most limited plane of motion of the ankle during the entire study period. Most limitations for both planes of motion were seen at 3 weeks post burn.

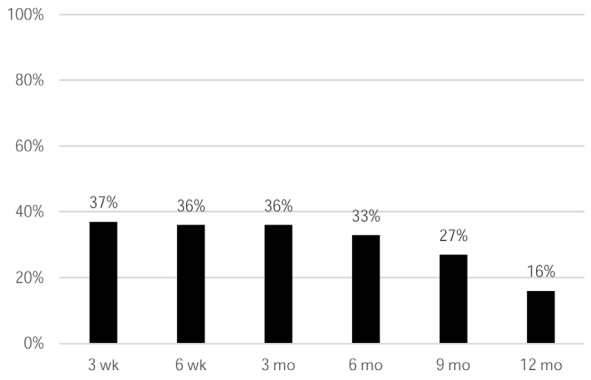

Fig. 1 – Mean percentage ROM limitations of all planes of motion grouped together over time (wk: weeks mo: months).

3.3. *Classifying the severity of ROM limitation per plane of motion*

The degree of ROM limitation per plane of motion at the specific timepoints during recovery are shown in Table 5. Per time point, the number of planes of motion that are unlimited or limited minorly, moderately or severely is presented.

As shown in this table, the planes of motion that were unlimited increased over time. At 12 months between 50–100% of all planes of motion were unlimited, with exception of the abduction of the shoulder, with just 47% unlimited. At 12 months after the burn injury, 12 out of 17 planes of motion demonstrated persistent joint limitations. These limitations concerned all planes of motion of the neck, all planes of motion of the upper extremity joints, the knee flexion and the dorsal flexion of the ankle. Five planes of motion were unlimited, all located at the lower extremity. From the 1720 limited planes of motion, 1359 (80%) had a minor or mild severity rating, indicating that most of the planes of motion were limited less than 50% of the full ROM during the entire period of recovery.

Table 4 – Mean (SD) limited ROM as percentage of the full ROM (wk: weeks, mo: months).

Plane of motion	3 wk	6 wk	3 mo	6 mo	9 mo	12 mo	Discharge
Neck extension	64 (29)	61 (28)	72 (23)	63 (30)	63 (25)	51 (20)	63 (24)
Neck latero-flexion	43 (19)	52 (19)	45 (18)	40 (13)	32 (9)	27 (7)	44 (15)
Neck rotation	39 (23)	52 (24)	43 (21)	39 (16)	32 (10)	29 (14)	41 (20)
Shoulder anteflexion	30 (23)	32 (23)	36 (22)	38 (18)	37 (13)	21 (13)	34 (26)
Shoulder abduction	31 (23)	35 (21)	42 (18)	37 (19)	35 (19)	21 (14)	40 (26)
Elbow flexion	12 (6)	12 (8)	17 (7)	17 (6)	12 (3)	8 (1)	15 (10)
Elbow extension	12 (5)	16 (9)	18 (8)	22 (13)	19 (11)	7 (1)	19 (14)
Elbow supination	32 (25)	32 (24)	34 (14)	46 (15)	37 (11)	16 (2)	33 (22)
Wrist flexion	33 (16)	30 (15)	33 (13)	29 (14)	27 (16)	23 (11)	29 (15)
Wrist extension	38 (20)	35 (18)	39 (22)	39 (20)	33 (17)	25 (15)	38 (22)
Hip abduction	47 (20)	40 (10)	35 (13)	32 (8)	28 (4)	0 (0)	35 (12)
Hip flexion	18 (6)	14 (11)	11 (3)	9 (1)	0 (0)	0 (0)	13 (5)
Hip extension	81 (15)	78 (15)	72 (25)	65 (26)	50 (7)	0 (0)	70 (18)
Knee flexion	27 (13)	21 (14)	16 (11)	13 (5)	11 (4)	10 (3)	26 (8)
Knee extension	11 (5)	11 (4)	9 (5)	8 (3)	7 (1)	0 (0)	10 (5)
Dorsal flexion	78 (24)	72 (30)	66 (29)	54 (26)	49 (21)	44 (17)	67 (21)
Plantar flexion	18 (9)	15 (3)	13 (2)	12 (1)	0 (0)	0 (0)	13 (4)

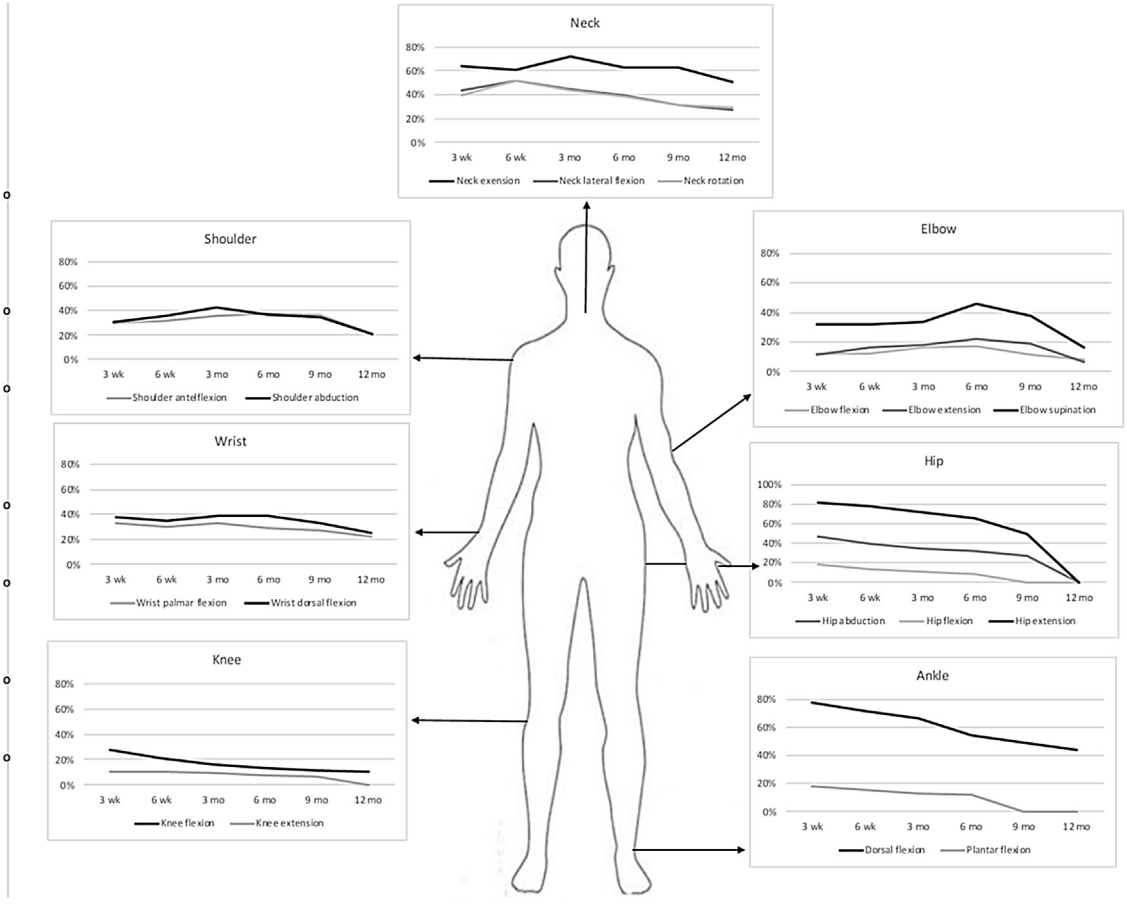

Fig. 3 – The course of the mean percentage ROM limitations per joint and plane of motion (wk: weeks, mo: months).

Only 94 of the limited planes of motion (5%) were classified as severe, indicating that the number of joints that were limited more than 75% of the full ROM were sparse. The hip extension at 3 weeks and the ankle dorsal flexion at 3 and 6 weeks demonstrated most limited planes of motion in the severe group.

3.4. *Comparing the upper- and lower extremity*

Comparing the course of the mean degree of ROM limitations of the joints of the upper- and lower extremity, showed that the lower extremity was more severely limited in the early phase of recovery than the upper extremity. Conversely, at 12

Table 5 – Prevalence of degree of ROM limitation per plane of motion (wk: weeks, mo: months).

	Unlimited						Minor <25%						Mild 26-50%						Moderate 51-75%						Severe 76-100%					
	3wk	6wk	3mo	6mo	9 mo	12mo	3wk	6wk	3mo	6mo	9mo	12mo	3wk	6wk	3mo	6mo	9mo	12mo	3wk	6wk	3mo	6mo	9mo	12mo	3wk	6wk	3mo	6mo	9m0	12
Neck extension	18%	27%	33%	50%	50%	70%	12%	0%	7%	0%	8%	0%	24%	27%	13%	21%	17%	10%	29%	27%	27%	14%	8%	10%	18%	20%	20%	14%	17%	
Neck lateroflexion	15%	28%	30%	50%	71%	82%	23%	16%	17%	12%	8%	12%	31%	24%	30%	15%	21%	6%	23%	28%	23%	19%	0%	0%	8%	4%	0%	4%	0%	
Neck rotation	14%	24%	28%	50%	67%	67%	29%	20%	21%	13%	10%	20%	32%	28%	34%	13%	19%	7%	18%	24%	17%	25%	5%	7%	7%	4%	0%	0%	0%	
Shoulder flexion	25%	29%	27%	43%	46%	55%	33%	32%	24%	16%	11%	34%	18%	27%	35%	32%	37%	10%	18%	7%	12%	9%	6%	0%	6%	5%	2%	0%	0%	
Shoulder abduction	18%	25%	29%	36%	36%	47%	41%	30%	20%	18%	42%	37%	22%	28%	35%	36%	11%	17%	16%	18%	16%	9%	11%	0%	4%	0%	0%	0%	0%	
Elbow flexion	52%	52%	53%	67%	75%	64%	40%	40%	32%	23%	19%	27%	8%	8%	15%	10%	6%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Elbow extension	57%	57%	49%	65%	74%	62%	43%	31%	39%	20%	18%	33%	0%	12%	11%	14%	9%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Elbow supination	51%	48%	48%	56%	64%	50%	37%	26%	18%	14%	9%	20%	3%	12%	23%	14%	21%	30%	5%	4%	10%	16%	6%	0%	3%	10%	0%	0%	0%	
Wrist flexion	46%	51%	46%	52%	68%	88%	22%	22%	20%	18%	17%	9%	21%	19%	21%	20%	11%	3%	12%	8%	13%	10%	4%	0%	0%	0%	0%	0%	0%	
Wrist dorsal flexion	39%	52%	34%	46%	49%	81%	20%	21%	21%	15%	22%	10%	26%	19%	23%	25%	18%	10%	10%	7%	17%	15%	10%	0%	4%	2%	4%	0%	0%	
Hip abduction	30%	46%	52%	76%	90%	100%	11%	17%	22%	8%	5%	0%	41%	29%	22%	12%	5%	0%	11%	8%	4%	4%	0%	0%	7%	0%	0%	0%	0%	
Hip flexion	25%	42%	48%	81%	100%	100%	54%	29%	28%	19%	0%	0%	21%	21%	16%	0%	0%	0%	0%	8%	8%	0%	0%	0%	0%	0%	0%	0%	0%	
Hip extension	22%	42%	41%	100%	95%	100%	4%	8%	26%	0%	0%	0%	4%	17%	19%	0%	5%	0%	26%	25%	7%	0%	0%	0%	44%	8%	7%	0%	0%	
Knee flexion	32%	48%	57%	62%	68%	71%	34%	24%	31%	38%	32%	29%	25%	18%	12%	0%	0%	0%	9%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Knee extension	67%	53%	63%	73%	86%	100%	33%	28%	26%	27%	14%	0%	0%	21%	7%	0%	0%	0%	0%	3%	5%	0%	0%	0%	0%	0%	0%	0%	0%	
Ankle plant. flexion	36%	56%	68%	59%	82%	100%	36%	37%	26%	32%	14%	0%	27%	7%	6%	9%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Ankle dorsal flexion	25%	41%	52%	39%	67%	71%	0%	3%	0%	9%	10%	0%	16%	21%	18%	35%	19%	24%	13%	7%	9%	4%	5%	5%	47%	28%	21%	13%	0%	

Legend: subdivision of the prevalence of limitation severity:
0% | < 26% | 26-50% | 51-75% | 76-100%

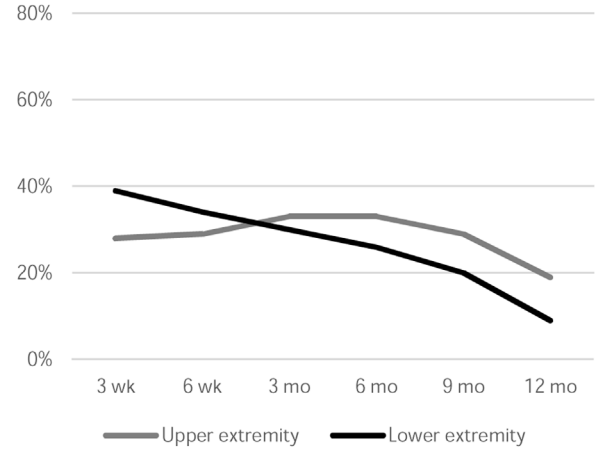

Fig. 4 – Mean percentage ROM limitation joints upper extremity and lower extremity (wk: weeks, mo: months).

months the upper extremity was more severely limited than the lower extremity. The turning point was between 6 weeks- and 3 months post burn (Fig. 4).

The classification of the degree of ROM limitation of the collected joints from the upper- and from the lower extremity is shown in Figs. 5 and 6.

4. Discussion

The objective of this study was to identify the course of the degree of joint limitations and their associated planes of motion after burn injuries. The findings of this study showed that a great variety exists between the course of the degree of ROM limitations over time between extremities, joints and planes of motion and the final development into a burn scar contracture. At 12 months, the degree of limitation of the joints of the upper extremity was more severe than of those of the lower extremity. The most severely limited joint was the neck, followed by the ankle, wrist and shoulder. For all planes of motion, neck extension was most severely limited, followed by the dorsal flexion of the ankle, neck lateral flexion, neck rotation and both planes of motion of the wrist. The least severely limited planes of motion were from the elbow and knee, while 5 planes of motion from the lower extremity were unlimited, among which all planes of motion of the hip.

Another point to consider is, from which moment in time, ROM limitations may be regarded as the result of a burn scar contracture. During recovery after burn injuries, multiple factors may lead to temporary ROM limitation. We considered ROM limitations at 12 months as persistent and as such could be defined as a burn scar contracture.

The finding that at 12 months the upper extremity is more severely limited than the lower extremity, does not mean that all planes of motion of the upper extremity were more severely limited than those from the lower extremity. The elbow extension for instance, which belongs to the more severely limited joint planes of motion of the upper extremity, was the least severely limited plane of motion of all, while the ankle dorsal flexion, which belongs to the less severely limited joint planes of motion of the lower extremity, was the most severely limited plane of motion of all. Thus, a great variety exists in the degree of limitation between the particular joints and planes of motion.

Looking at the individual joints and their associated planes of motion showed that neck extension is by far the most severely limited plane of motion during the entire study period, followed by rotation and lateral flexion, which are nearly equally limited. The shoulder is generally considered one of the joints with most severe limitation. However, this needs to be regarded with some reserve. At 12 months, the mean limited ROM of the ante-flexion and abduction is 38.4°, which is indeed the highest limitation in degrees compared to all other joints. However, taking into account that the

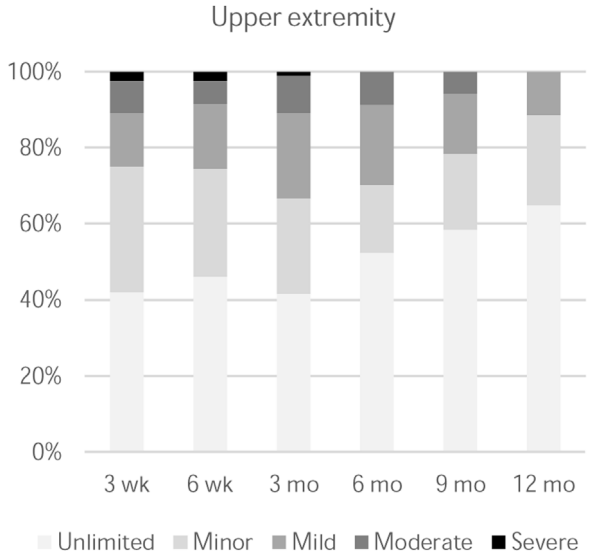

Fig. 5 – Classification mean ROM limitations joints upper extremity.

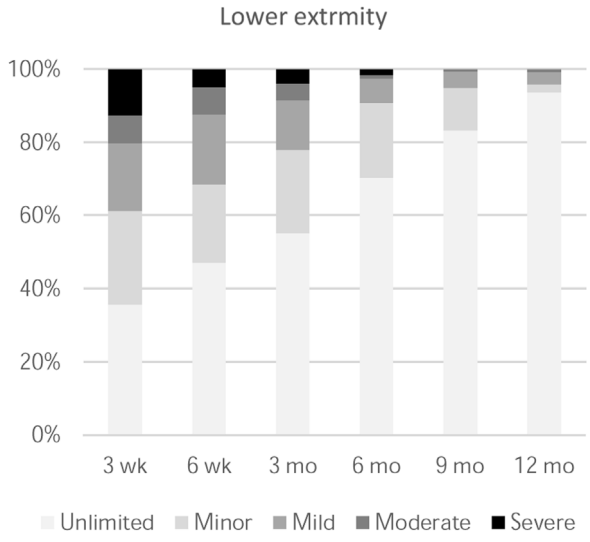

Fig. 6 – Classification mean ROM limitations joints lower extremity.

anteflexion and abduction of the shoulder have the highest normal full ROM of 180°, the limitation of 38.4° corresponds with 21.3% of the full ROM. Thus, in terms of severity, compared to all other planes of motion, it could be classified as minor. The same holds true for the elbow. Loss of extension as a result of a developing flexion burn scar contracture is regarded as a high-risk complication in burn care rehabilitation. Non-surgical interventions like extension splints and stretching exercise therapy are widely used to prevent or restore this complication. Elbow extension, however, was the least severely limited plane of motion related to all other planes of motion. Furthermore, at 12 months elbow flexion was nearly as limited as extension and the most severely limited plane of motion of the elbow was in fact supination. Despite the fact that flexion of the elbow is nearly equally limited at 12 months, it seems not to receive the same attention as elbow extension. The application of flexion splints is not a primary choice and as far as we know seldomly used. The question arises, why so much attention is paid in the acute phase to prevent or restore a limited elbow extension. The study of Oosterwijk et al. [23] showed that maximal elbow extension is not often necessary, with exception of reaching and putting on shoes and socks. On the other hand, many daily activities need flexion ROM between 130 and 150°, especially to fulfil tasks of personal care, like feeding, washing, hair care and the use of a cellular phone.

Therefore, it is remarkable that reconstructive surgery procedures of the elbow, are mainly focused on restoring the extension of the elbow. Reconstructive surgery procedures to restore exclusively the supination or flexion of the elbow are sparse.

At the wrist, at 12 months, the most severely limited plane of motion was extension. This corresponds with the generally accepted view, that planes of motion towards extension are more susceptible for ROM limitation than the planes of motion towards flexion. However, concerning the wrist, palmar flexion is just slightly less limited than extension. This is in line with the findings at the elbow. In both joints the degree of limitation toward extension and flexion is nearly similar. Nevertheless, rehabilitation interventions are mainly focused on preventing the loss of extension.

From all joints the hip demonstrated the greatest improvement of joint limitation over time and at 12 months all planes of motions of the hip were unlimited. The high degree of limitation of the hip extension at 3 weeks may be explained by the fact that in the acute phase patients are lying supine most of the time during periods of less activity, by which extending the hip is hampered. Furthermore, by mobilization of patients into a chair, prolonged periods in sitting position promotes the flexion of the hip and prevents hip extension. However, as soon as the patient starts mobilization in the upright position like standing and ambulation, extension will be increasingly involved in daily activities, causing a gradually correction of this limitation. Furthermore, it must be considered, that the full ROM of the extension of the hip is just 20°, which is not a great limitation to redress.

From the knee, an extension limitation because of a flexion contracture is clinically regarded as a high-risk complication. Which is confirmed by the generally accepted anti contracture treatment policy, to position and splint burned knees preventively and therapeutically in extension [24,25].

However, at 12 months post burn the knee extension showed a full ROM, while the knee flexion was still limited. Also, at discharge, flexion of the knee was still twice as much limited than extension. Apparently, a flexion limitation of the knee is clinically not regarded as a high-risk factor for functional disabilities in the long term. In addition, reconstructive surgery procedures to restore a flexion limitation of the knee are sparse and are mainly focused on restoring the knee extension [26–29].

The difference in the course of the degree of limitation of the particular planes of motion of a joint is most pronounced in the ankle. The dorsal flexion of the ankle is significantly more severe limited than the plantar flexion during the entire period of recovery. A possible explanation could be the musculo-

skeletal imbalance in the ankle joint of postural and phasic muscles, which are located on opposing sides of the agonist-antagonist relationship. Postural muscles tend to shorten in response to inactivity, whereas phasic muscles tend to lengthen and weaken [30,31]. For the ankle joint this means that the postural muscle, the triceps surea, will shorten, while the phasic muscles of the ventral side of the lower extremity will lengthen and weaken. As a result, the foot will be forced toward the plantar flexion position. During periods of inactivity, when patients lie supine, the foot is the distal part of a combination of connecting joints from the lower extremity, which is not hindered by an opposing resistance and therefore can move freely towards plantar flexion.

Regarding the mechanism of musculo-skeletal imbalance between postural and phasic muscles, it is worth to consider if burn rehabilitation interventions should not be focused more on strengthening the weakened phasic muscles and stretching and relaxing the hypertonic postural muscles, to regain the musculo-skeletal balance again. Another interesting question is, if the imbalance between postural and phasic muscles contributes to the development of burn scar contracture. However, this was not the scope of this study and deserves further investigation in our opinion.

Despite the rather high dorsiflexion limitation of the ankle at 12 months, intensive rehabilitation- or surgical interventions at that time are scarce. This seems to indicate that this limitation does not interfere in most daily activities like, walking, standing up from a chair, stair climbing, cycling etc. It is likely, that for more specific hobby-, sport or occupational activities, surgical-and/or non-surgical interventions may be indicated.

Following several studies that used discharge as reference for the degree of limitation of a burn scar contracture, ROM assessments at discharge were also included in this study.

Comparison of the degree of joint limitations at discharge and at 12 months after injury showed that the ranking of the degree of limitation at 12 months is not a copy of the limitations at discharge. Therefore, the degree of ROM limitations at discharge are no reliable predictors for the degree of limitation over time. In our opinion, the degree of ROM limitations found at 12 months provide more relevant information about planes of motions that may be considered as persistent limitations and as such may be claimed as the result of a burn scar contracture.

Having determined the limitation of joints and planes of motion, we intended to classify this in terms of the degree of limitation. However, a standard classification scale or system to interpret the degree of joint limitation is not available in burn care. Therefore, the general interpretation of degree of limitation has a variable subjectivity or is classified by own description- and rating classification systems [32,33]. Korps found seven studies which classified the degree of limitation of a burn scar contracture. Most of these classification systems, are based on a mathematical subdivision of the full ROM in a certain degree of severity and not related to functional abilities or disabilities. Likewise, in the current study, we categorized the number of planes of motion, according to our own severity rating system, as unlimited or if they were limited, classified as minor, mild, moderate or severe (Table 5). Currently, there is an increasing attention in the field of rehabilitation on describing and classifying the degree of ROM limitation of planes of motion in terms of functionality [23,33–35]. Therefore, future research in burn care rehabilitation is needed to provide guidelines for interpreting the degree of joint limitation related to standardized functional outcome measures.

Furthermore, it should be noted that the ROM measurements of this study were based on the prevailing goniometric standardized protocols of Norkin and White [20] at that time.

However, with today's wisdom concerning the cutaneo-kinimatic (CKM) influence of adjacent cutaneous functional units (CFU's) [36,37] and the position of adjacent joints on the ROM, future studies evaluating ROM limitations after burn injuries should definitely consider the concept of the revised goniometric protocol of Parry et al. [38].

For clinical practice it is important to identify which planes of motion are (most) predisposed for persistent ROM limitations in the long term. Because these planes of motion should be regarded as the result of persistent burn scar contracture. At 12 months most planes of motion from the upper part of the body are most predisposed for severe joint limitation.

The neck extension, neck rotation, neck lateral flexion, both planes of motion from the wrist and the shoulder are listed at the top 8 of most severe limited planes of motion.

The only plane of motion from the lower part of the body in this list is the dorsal flexion of the ankle. This is, after the neck extension, the second most severe limited plane of motion.

Indicating, that during the entire period of recovery, rehabilitation interventions should mainly be focused on these planes of motion, regardless the measure of severity of all particular planes of motion in the acute phase.

In addition, it is remarkable that the planes of motion of the elbow and knee have a low level of ROM severity compared to all other planes of motion, in as well the acute phase as in the long term. While these joints are generally regarded as high risk for bur scar contracture.

4.1. *Limitations*

As shown in the study of Schouten et al., multi-joint burns and burns across or adjacent to the joints influence the prevalence of ROM limitations [8]. However, to what extent this applies to the degree of ROM limitation of the involved joints could not be established in this study. In addition, follow-up lasted until 12 months after injury, whereas it can be questioned if for all patients, scars had matured by then. Although scar maturation is the preferred endpoint, there is much individual variation, and as it is, there were already missing data, because patients could not be assessed, or had already been discharged from clinical follow-up.

5. Conclusion

The degree of ROM limitation of all joints diminished overtime and a part of them even normalized to the full ROM. In general, joints of the upper extremity were more severely limited than those from the lower extremity. Recovery of the degree of limitation however varied considerably between extremities,

joints and planes of motion. The degree of ROM limitations in the acute phase and at discharge was not predictive for degree of ROM limitation in the long term. At 12 months the neck, ankle, wrist and shoulder were the most severe limited joints. This study underscores the importance of longitudinal studies in this area. Future studies should relate the severity of ROM limitation to functional impact.

Conflict of interest statement

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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