

PROTOCOL INFORMATION

FULL/LONG TITLE OF THE STUDY: The use of neuromuscular electrical **STIM**ulation as a treatment for sarcopenia in people on **HaemoD**ialysis: Work packages 2-4

Work package 2: Efficacy study (Randomised Controlled Trial)

Work package 3: Health economic evaluation

Work package 4: Optional mechanistic study

SHORT STUDY TITLE / ACRONYM: STIM-HD

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This protocol has regard for the HRA guidance and the University of Leicester Sponsor Standard Operating Procedures (SOPs).

SIGNATURE PAGE

The undersigned confirm that the following protocol has been agreed and accepted and that the Chief Investigator agrees to conduct the study in compliance with the approved protocol and will adhere to the principles outlined in the UK Policy Framework for Health and Social Care Research (2017), GCP guidelines, the Sponsor's (and any other relevant) SOPs, and other regulatory requirements.

I agree to ensure that the confidential information contained in this document will not be used for any other purpose other than the evaluation or conduct of the clinical investigation without the prior written consent of the Sponsor.

I also confirm that I will make the findings of the study publicly available through publication or other dissemination tools without any unnecessary delay and that an honest accurate and transparent account of the study will be given. Any discrepancies and serious breaches of GCP from the study as planned in this protocol will be explained.

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LIST OF ABBREVIATIONS

AE	Adverse Event
AR	Adverse Reaction
BIA	Bioelectrical Impedance Analysis
CI	Chief Investigator
CKD	Chronic Kidney Disease
CONSORT	Consolidated Standards of Reporting Trials
CRF	Case Report Form
DSMC	Data Safety Monitoring Committee
eGFR	estimated Glomerular Filtration Rate
EME	Efficacy and Mechanism Evaluation
EMG	Electromyography
EQ-5D-5L	EuroQol EQ-5D-5L – Quality of Life questionnaire
EWGSOP2	European Working Group on Sarcopenia in Older People
FEV1	Forced expiratory volume in 1 second
GCP	Good Clinical Practice
GP PAQ	General Practice Physical Activity Questionnaire
HbA1c	Haemoglobin A1C
HD	Haemodialysis
ICF	Informed Consent Form
ISF	Investigator Site File
ITT	Intention-to-treat analysis
ISWT	Incremental Shuttle Walk Test
KDQoL	Kidney disease quality of life
LCTU	Leicester Clinical Trials Unit
MCID	Minimal clinically important difference
MedDRA	Medical Dictionary for Regulatory Activities
NIHR	National Institute for Health and Care Research
NMES	Neuromuscular electrical stimulation
PI	Principal Investigator
PIS	Participant Information Sheet
PPIE	Patient Participation, Involvement and Experience
PBMC	Peripheral blood mononuclear cells
QoL	Quality of Life
RCT	Randomised Control Trial
RDN	Research Delivery Network
REC	Research Ethics Committee
RNA	Ribonucleic acid
RPE	Rating of perceived exertion
SAE	Serious Adverse Event
SAP	Statistical Analysis Plan
SAR	Serious Adverse Reaction
SARC-F	Strength, Ambulation, Rising from a chair, Stair climbing and history of Falling
SarQoL	Sarcopenia related quality of life
SONG-HD	Standardised Outcomes in Nephrology - Haemodialysis
SOP	Standard Operating Procedure
SPPB	Short Physical Performance Battery
STS5	Sit to Stand 5
SUSAR	Suspected Unexpected Serious Adverse Reaction
TMF	Trial Master File
TMG	Trial Management Group
TSC	Trial Steering Committee
UKCRC	UK Clinical Research Collaboration
UKRR	UK Renal Registry
VO _{2Peak}	Maximal Exercise Capacity
WBC	White blood cells

KEY WORDS

Skeletal muscle wasting, physical function, chronic disease, quality of life.

STUDY SUMMARY

Study Title	The use of neuromuscular electrical STIMulation as a treatment for sarcopenia in people on HaemoDialysis – STIM-HD	
Study Design	Prospective, open-label, assessor blind, two-arm, multi-centre, Randomised Controlled Trial	
Study Participants	Adult (≥18 years) haemodialysis patients, undertaking HD for >3-months (home or unit-based), with sarcopenia diagnosed by low handgrip strength OR prolonged sit to stand 5 score on patient screening.	
Planned Sample Size	228 (114 to the intervention arm and 114 to the control arm) Sub-group for optional mechanistic outcomes: • 50 participants (25 in each arm) will take part in neuromuscular assessments (high-density surface and intramuscular electromyography); • 24 participants (12 per arm) will take part in skeletal muscle biopsies.	
Follow-up Duration	6 months	
Planned Study Period	3.5 years	
	Objectives	End Points/Outcome Measures
Primary	To measure the effect of a 3-month (12-week) NMES programme on muscle strength, the core manifestation of sarcopenia, compared with standard care for HD patients.	- Isometric strength (Nm)
Secondary	To measure the effect of a NMES programme on QoL. To evaluate the cost-effectiveness of a NMES programme compared with standard care for patients with end-stage kidney disease within an NHS costing perspective To investigate if NMES results in neuromuscular adaptations and changes in muscle phenotype To investigate the effect upon muscle mass, physical function and physical activity levels To measure the safety of the intervention	- Kidney Disease Quality of Life (KDQoL-SF) questionnaire - EuroQoL EQ-5D-5L - Resource use questionnaire - Skeletal muscle biopsy analysis - High density and Intramuscular Electromyography - Evoked responses to femoral nerve stimulation - Ultrasound - 6-minute walk test or ISWT as space allows - Short Physical Performance Battery - Bioelectrical impedance - SARC-F questionnaire - SarQoL questionnaire - GP PAQ questionnaire - Accelerometry - Sleep diary - Handgrip Strength - Adverse Events relating to the intervention

FUNDING AND SUPPORT IN KIND

FUNDER(S) (Names and contact details of ALL organisations providing funding and/or support in kind for this study)	FINANCIAL AND NON-FINANCIAL SUPPORT GIVEN
NIHR EME Programme Funder reference: NIHR158852	Financial support

ROLE OF STUDY SPONSOR

The Sponsor of this research is the University of Leicester. The University of Leicester is responsible for the design, management and outputs of the research. Participating NHS sites are responsible for the conduct of the study within their organisation.

The Research Governance Office review and approve all iterations of the protocol as part of their initial Sponsor review and amendment review process. Further information is available from our Sponsor Standard Operating Procedures [webpage](#).

ROLE OF COLLABORATOR(S)

Dr Gordon McGregor and Professor Indranil Dasgupta will support recruitment at University Hospital Coventry and Warwickshire and University Hospitals Birmingham respectively.

Professor Jonathan Folland and Dr Jakob Skarabot will lead the mechanistic neuromuscular adaptation investigation assessments.

Professor Nicola Cooper will oversee the health economic analysis.

Mr Fez Awan will lead the PPIE work throughout the study.

ROLES AND RESPONSIBILITIES OF TRIAL MANAGEMENT COMMITTEES/GROUPS & INDIVIDUALS

The Leicester Clinical Trials Unit (LCTU) is providing support for this study. It is a UKCRC registered Clinical Trials Unit with extensive experience of handling data from large multi-centre trials. The LCTU has been involved in the development and design of the protocol since conception of this study and will facilitate study data collection, statistical analysis and reporting and associated quality assurance. The study is sponsored by the University of Leicester.

A Trial Management Group (TMG) including the CI, Trial Co-ordinator, co-applicants and members of the LCTU will direct and oversee the day-to-day running of the study and will meet according to its demands. The TMG will highlight any key day-to-day study-related issues and monitor progress of all research activities to ensure that the study is being delivered on time and to target.

An independent Trial Steering Committee (TSC), with an independent Chair, Expert Statistician, Health Economist, Clinician with relevant expertise, and Lay Representative will be convened to oversee, advise on and monitor the study. A Sponsor representative and a Research Network representative will also be invited to attend as non-voting observers. The TSC will meet at least annually or as required throughout the study. Meeting minutes will be sent to all members, the Sponsor, and the funder, and retained in the Trial Master File (TMF).

An independent Data Safety Monitoring Committee (DSMC), with an independent Chair, Expert Statistician, and a Clinician with relevant expertise will be convened to monitor the study data and make recommendations to the TSC on whether there are any ethical or safety concerns. The DSMC will meet at least annually or as required throughout the study. Meeting minutes will be sent to all members, the Sponsor, the funder, and the TSC, and retained in the TMF.

STUDY FLOW CHART

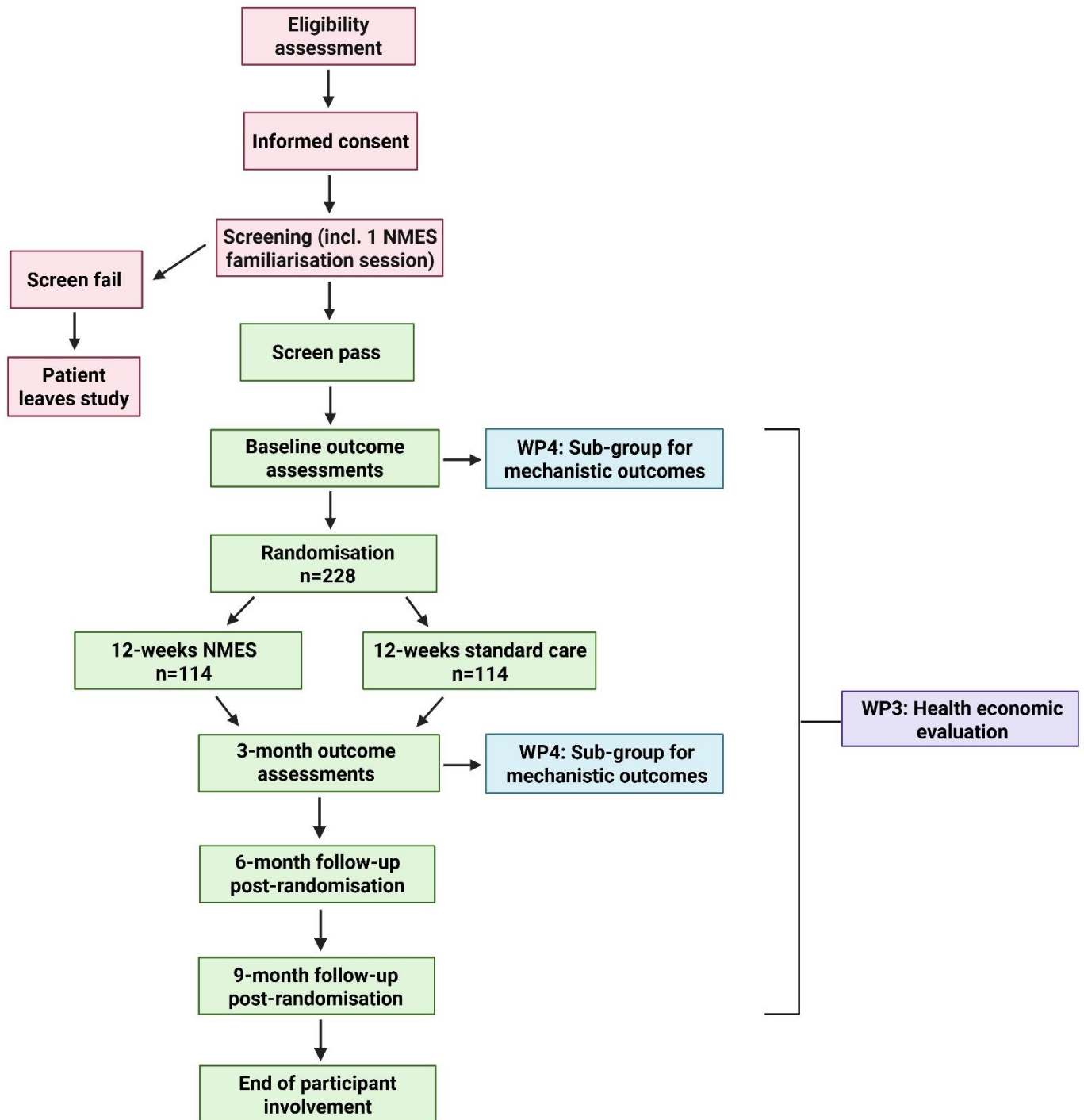


Figure 1: Flow of participants through the study

1. BACKGROUND

Sarcopenia is characterised by a loss of muscle strength (the most important characteristic), and mass, as well as low physical performance, and is now classified as a disease in its own right (1). Although often associated with ageing, it is also recognised as a complication of other long term health conditions and is associated with worse clinical outcomes, including poor quality of life (QoL), higher hospitalisation rates and increased mortality. The annual cost of sarcopenia to the NHS is around £2.5 billion (2).

Chronic kidney disease (CKD) is a public health emergency that threatens to overwhelm the NHS, affecting around 14% of adults in England (3). When kidney function drops to the point it can no longer sustain life, a form of renal replacement therapy is required, for example dialysis. There are currently 30,000 adults and children receiving dialysis in the UK, with this number projected to increase to 143,000 by 2033 (4). Sarcopenia is a frequent complication of CKD, affecting around 28% of people with more advanced disease (5-7). Data from our cohort of patients with kidney failure on haemodialysis (HD) shows it is common; 39% of patients have confirmed sarcopenia, a further 10% have probable sarcopenia, and 16% have severe sarcopenia (unpublished observations). Systematic reviews specifically in CKD patients have shown sarcopenia is associated with falls, fractures, cardiovascular events and mortality (7, 8), demonstrating its clinical importance. In the UK, sarcopenia is diagnosed according to the algorithm described and recently updated by the European Working Group on Sarcopenia in Older People (9) (EWGSOP2). Depending upon performance in a range of tests, people can be diagnosed with either probable sarcopenia (the point at which guidelines suggest an intervention should be targeted), confirmed sarcopenia, or severe sarcopenia.

2. RATIONALE

The mainstay of treatment for sarcopenia is lifestyle modification, principally exercise interventions. Exercise has been shown to improve muscle mass and strength in people with sarcopenia on haemodialysis (10, 11). Recent national guidelines from the UK Kidney Association, endorsed by the National Institute for Health and Care Excellence (NICE) and led by authors from this group, routinely recommend dialysis unit-based exercise programmes. Unfortunately, although exercise programmes are likely to be more beneficial from both a cardiovascular and a musculoskeletal point of view, as many as 74% of HD patients are unable or unwilling to participate in such programmes (12, 13). In the recently published CYCLE-HD and PEDAL trials (both undertaken by this group), which investigated dialysis unit-based exercise interventions, of the 2835 patients screened, over 2100 were deemed ineligible (12, 13). Many of the patients were severely deconditioned and adherence to the exercise interventions was extremely low (47% of exercise training sessions prescribed were completed and only 18% adhered exactly to the prescription) (14). Therefore, an accessible alternative is clearly needed.

Neuromuscular electrical stimulation (NMES) is a treatment whereby the application of intermittent electrical stimuli generates involuntary muscle contractions, and might serve as an 'exercise mimetic'. This therapy is used widely in physiotherapy rehabilitation programmes (15, 16) and is now being used in clinical settings, including in intensive care units (17). NMES could represent an ideal alternative for people on HD who are unable to exercise and therefore prevent the inevitable decline in muscle mass and strength that leads to sarcopenia.

3. RESEARCH QUESTION/OBJECTIVES AND OUTCOME MEASURES/ENDPOINTS

Research Question: Can NMES be used as a therapy for sarcopenia in people on HD?

Aim: To test the clinical efficacy of NMES as a therapy for sarcopenia in people on HD.

Objectives:

- To measure the effect of a 3-month (12-week) NMES programme on muscle strength, the core manifestation of sarcopenia, compared with standard care for HD patients
- To measure the effect of a NMES programme on QoL
- To measure the effect of a NMES programme on muscle size and measures of physical function
- To evaluate the cost-effectiveness of a NMES programme compared with standard care for patients with end-stage kidney disease within an NHS costing perspective
- To investigate if NMES results in neuromuscular adaptations and changes in muscle phenotype

3.1 Primary objective

Primary Objective: To measure the effect of a 3-month (12-week) NMES programme on muscle strength, the core manifestation of sarcopenia, compared with standard care for HD patients.

Null hypothesis: There will be no difference in the change in muscle strength from baseline to 3 months between NMES and standard care groups.

Experimental hypothesis: Three months of NMES will create a significant increase in muscle strength compared to the standard care group.

3.2 Secondary objectives

The secondary objectives are:

- To measure the effect of a NMES programme on QoL
- To evaluate the cost-effectiveness of a NMES programme compared with standard care for patients with end-stage kidney disease within an NHS costing perspective
- To investigate if NMES results in neuromuscular adaptations and changes in muscle phenotype
- To measure the effect of a NMES programme on muscle size and measures of physical function
- To measure the safety of the intervention

3.3 Outcome measures/endpoints

3.3.1 Primary endpoint/outcome

Primary Endpoint: The primary outcome is change in muscle strength measured using isometric dynamometry from baseline to 3-months.

3.3.2 Secondary endpoints/outcomes

Secondary endpoints:

To compare between randomised groups;

1. Additional efficacy measures
 - a. Muscle size and architecture (measured cross-sectional area of rectus femoris using ultrasound, muscle thickness and angle of fibre pennation)
 - b. Lower-extremity strength, functional capacity, and balance: The short physical performance battery (SPPB)
 - c. Cardiovascular functional capacity and endurance: the 6-minute walk test (or incremental shuttle walk test in the event of space constraints)
 - d. Body composition (including lean muscle mass) using bioelectrical impedance
 - e. GP Physical Activity questionnaire
 - f. Hand Grip strength
 - g. Accelerometry and sleep diary
 - h. Isometric rate of force development
2. Measures of QoL and social functioning
 - a. The Kidney Disease Quality of Life tool (KDQoL-SF)
 - b. EQ-5D-5L, a generic multi-attribute health related QOL questionnaire for use in cost utility analysis (health economic analysis).
 - c. Levels of fatigue (using SONG-HD score)
 - d. SARC-F (validated questionnaire recommended as the screening instrument for sarcopenia in clinical practice by the European Working Group)
 - e. Sarcopenia and quality of life (SarQoL questionnaire)
3. NHS Resource use (collected via participant self-completion questionnaire), to be combined with NHS unit costs for use in cost utility analysis
4. Measures of process and tolerability
 - a. Number of patients eligible, approached and recruited
 - b. Dropout rates and movement between allocated study groups
 - c. Tolerability of the intervention to include number of neuromuscular stimulation sessions undertaken and the total time per session (up to 30-minutes).
5. Measures of safety
 - a. Adverse events relating to the intervention
6. Measures of neuromuscular adaptations and muscle phenotype
 - a. High-density surface electromyography, for assessment of quadriceps motor unit recruitment and discharge rate, and conduction velocity during sub-maximum and maximum knee extension contractions.

- b. Intramuscular electromyography, for assessment of motor unit potential jiggle and segment jitter, electrophysiological markers of neuromuscular junction transmission stability.
- c. Femoral nerve stimulation, for assessment of quadriceps contractile properties.
- d. Skeletal muscle biopsy analysis

3.4 Table of endpoints/outcomes

Objectives	Outcome Measures	Timepoint(s) of evaluation of this outcome measure (if applicable)
Primary Objective: To measure the effect of a 3-month (12-week) NMES programme on muscle strength, the core manifestation of sarcopenia, compared with standard care for HD patients	Isometric strength (Nm)	Screening visit (as a familiarisation session), baseline, 3, 6, 9 months post randomisation
Secondary Objectives To measure the effect of a NMES programme on QoL To evaluate the cost-effectiveness of a NMES programme compared with standard care for patients with end-stage kidney disease within an NHS costing perspective – health economic evaluation To measure the effect of a NMES programme on muscle size and measures of physical function	The Kidney Disease Quality of Life tool (KDQoL-SF) EQ-5D-5L questionnaire Resource use questionnaire Muscle quality and architecture (e.g. echo intensity and angle of pennation by ultrasound) Muscle mass (thickness and cross-sectional area by ultrasound) Handgrip strength by dynamometry Lower-extremity strength, functional capacity, and balance (using the short physical performance battery (SPPB)). Cardiovascular functional capacity and endurance (by the 6-minute walk test or the ISWT if space constraints) Body composition (using bioelectrical impedance) Isometric rate of force development Physical activity levels (using GP Physical Activity questionnaire and accelerometry)	Baseline, 3, 6, 9 months post randomisation Baseline, 3, 6, 9 months post randomisation Baseline and 3 months Baseline, 3, 6, 9 months post randomisation

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4. STUDY DESIGN

STIM-HD is a prospective, open-label, assessor blind, two-arm, multi-centre, randomised controlled trial. Assessments will be made at baseline and at 3-months post randomisation (i.e. at the end of the intervention period) and at 6 and 9 months post randomisation.

In total, 228 participants (114 per arm, adults with end-stage kidney disease and sarcopenia, who are receiving long-term haemodialysis either in hospital, or at home) will be recruited and randomised to receive either 3-months (12 weeks) of NMES or standard care. In addition, 50 participants (25 in each arm) will also take part in the neuromuscular assessments (high-density surface and intramuscular electromyography and 24 participants (12 per arm) for a skeletal muscle biopsy.

Participants will be recruited from approximately 5 hospital and satellite haemodialysis centres, with additional reserve units available if required, from up to 5 NHS Trusts.

5. STUDY SETTING

STIM-HD will be run as a multi-centre study in secondary care across up to 5 NHS Trusts.

6. PARTICIPANT ELIGIBILITY CRITERIA

6.1 Inclusion criteria

1. Undertaking HD for >3-months (home or unit based)
2. Age ≥ 18 years
3. Has sarcopenia diagnosed by either:
 - Low handgrip strength (<27kg for men and <16kg for women) **OR**
 - Prolonged Sit to Stand 5 score (>15 seconds for both men and women) if handgrip strength is above the sarcopenia threshold
4. Able to give written informed consent

6.2 Exclusion criteria

1. Contra-indications to neuromuscular electrical stimulation therapy including:
 - i. Lower limb amputation
 - ii. Active skin ulceration or infection
 - iii. Critical lower limb ischaemia, including pain at rest or functional impairment that precludes completion of study assessments
 - iv. Lower limb deep vein thrombosis <3-months
 - v. Cardiac pacemaker or implantable cardiac defibrillator
2. Conditions known to cause muscle wasting
 - i. Known neuromuscular disease
 - ii. Active malignancy
3. Scheduled for living donor kidney transplant or plan to change dialysis modality or centre in the next 6-months
4. Life expectancy of <6-months
5. Current participation in an interventional trial with conflicting therapies or outcomes
6. Unable to give written informed consent.
7. Vascular access in the lower limbs that may interfere with intervention delivery

Muscle biopsy and intramuscular electromyography specific exclusion criteria

1. On anti-coagulation (e.g. warfarin / Direct Oral Anticoagulant).
2. Bleeding disorder (e.g. haemophilia).
3. On high dose statins (i.e. atorvastatin 80mg), growth hormone or corticosteroids.
4. Deep vein thrombosis within the last 3 months.

7. STUDY SCHEDULE

Visits will be broken up as the participant wishes. The 3-month follow up assessments should be carried out within 2 weeks of completing the intervention, or standard care period where possible. The timeframe from randomisation to commencing NMES will be **2 weeks**. Instances where this timeframe is exceeded will be reported as protocol deviations.

It is expected that each participant will partake in the study for 10-months in total. 3-months is the end of the intervention period, 6- and 9-months are follow-up.

7.1 Schedule of procedures - NMES group

	Screening	Baseline	Each dialysis session during 3-month (12-week) intervention period	Weekly	Monthly	3-months	6-months	9-months
Invitation	1							
Eligibility assessment	1							
Informed consent	1							
Handgrip strength OR STS5 for screening purposes	1							
Medical history		1						
Handgrip strength for outcome measures		1				1	1	1
Isometric muscle strength	1 (familiarisation session)	1				1	1	1
Isometric rate of force development	1 (familiarisation session)	1				1	1	1
Muscle size and architecture (ultrasound)		1				1	1	1
Short Physical Performance Battery		1				1	1	1
6-minute walk test/ISWT		1				1	1	1
Bioelectrical Impedance Analysis		1				1	1	1
EQ-5D-5L		1				1	1	1
KDQoL-SF		1				1	1	1
SARC-F		1				1	1	1
SarQoL		1				1	1	1
GPPAQ		1				1	1	1
SONG HD - Fatigue		1				1	1	1
Resource use questionnaire and optional diary		1				1	1	1
Accelerometry		1				1	1	1
Sleep diary		1				1	1	1
Blood sample		1*			1 (routine)	1*	1*	1*

					clinical care)			
Neuromuscular electrical stimulation	1		1					
RPE			1					
Blood lactate measurement				1				
Skeletal muscle biopsy – NMES group n=12 (Optional)		1				1		
High Density and Intramuscular electromyography n=25 (Optional)		1				1		
Sub-maximum contractions (for EMG recordings) n=25 (Optional)	1 (familiarisation session)	1				1		
Evoked contractions (femoral nerve stimulation) n=25 (Optional)		1				1		
Capture of routine clinical data^		1			1	1	1	1
Adverse event assessments		1	1			1	1	1
Inform GP of study participation		1						

*Represents research blood samples drawn during routine clinical testing. ^Represents routinely collected serum blood results and dialysis data on all dialysis units.

7.2 Schedule of procedures – Control group

	Screening	Baseline	Each dialysis session during 3-month (12-week) intervention period	Monthly	3-months	6-months	9-months
Invitation	1						
Eligibility assessment	1						
Informed consent	1						
Handgrip strength) OR STS5 for screening purposes	1						
Medical history		1					
Handgrip strength for outcome assessments		1			1	1	1
Isometric muscle strength	1 (familiarisation session)	1			1	1	1
Isometric rate of force development	1 (familiarisation session)	1			1	1	1
Muscle size and architecture (ultrasound)		1			1	1	1

Short Physical Performance Battery		1			1	1	1
6-minute walk test/ISWT		1			1	1	1
Bioelectrical Impedance Analysis		1			1	1	1
EQ-5D-5L		1			1	1	1
KDQoL-SF		1			1	1	1
SARC-F		1			1	1	1
SarQoL		1			1	1	1
GPPAQ		1			1	1	1
SONG HD - Fatigue		1			1	1	1
Resource use questionnaire and optional diary		1			1	1	1
Accelerometry		1			1	1	1
Sleep diary		1			1	1	1
Blood sample		1*		1 (routine clinical care)	1*	1*	1*
Neuromuscular electrical stimulation	1						
Skeletal muscle biopsy – Control group (n=12) (Optional)		1			1		
High-density surface and Intramuscular electromyography N=25 (Optional)		1			1		
Sub-maximum contractions (for EMG recordings) n=25 (Optional)	1 (familiarisation session)	1			1		
Evoked contractions (femoral nerve stimulation) n=25 (Optional)		1			1		
Capture of routine clinical data [^]		1		1	1	1	1
Adverse event assessments		1	1		1	1	1
Inform GP of study participation		1					

**Represents research blood samples drawn during routine clinical testing. [^]Represents routinely collected serum blood results and dialysis data on all dialysis units.*

8. RECRUITMENT

8.1 Participant identification

Potential participants will be identified by a member of the clinical team based upon the exclusion and inclusion criteria. They will be recruited via the following routes:

1) During or before a routine outpatient clinical appointment. For individuals that may be eligible to take part, participant invitation letters will be sent along with appointment letters. The clinician will formally approach the person about the study during their clinic visit and will provide the individual with an invitation letter and a brief explanation of the study. If they are interested to find out more, they will have the opportunity to speak to a member of the research team who will give them a participant information sheet and answer any questions they have. If an individual has not been identified prior to their planned clinic appointment, but the clinician deems them to be eligible they will be given the participant invitation letter together with the participant information sheet and a brief

explanation of the study. If they are interested, they will then be given the opportunity to speak to a member of the research team;

2) During a dialysis session or ward round on the unit. The clinician will speak to the individual either as part of a normal ward round, or as a separate initial approach about STIM-HD. They will provide the individual with an invitation letter and the participant information sheet, and provide a brief explanation of the study. If they are interested to find out more, they will have the opportunity to speak to a member of the research team who will answer any questions they have.

8.2 Screening and eligibility assessment

Potential participants will be screened for eligibility by a member of the clinical team using their most recent laboratory tests and medical history.

8.3 Consent

Potentially eligible participants will be initially approached by a member of their usual healthcare team to see if they would like to take part in the study. Patients will be provided with a PIS to take home, or this can be emailed to them. A member of the research team will speak to them a few days later to discuss the exact nature of the study, the implications and constraints of the protocol, and any risks involved in taking part, at a time convenient for the patient, most likely whilst they are receiving dialysis to answer any further questions and to confirm their decision regarding participation. They will be given as much time as they wish to consider their participation and the opportunity to question their GP or other independent parties. If the individual would like to take part, the research team will then organise a suitable time for them to sign the consent form and to complete the assessments. The PIS will clearly state that the participant is free to withdraw from the study at any time for any reason without prejudice to future care, and with no obligation to give the reason for withdrawal.

The participant must personally sign and date the latest approved version of the informed consent form before any study specific procedures are performed. Written Informed Consent will be obtained by means of a signed and dated up to date version of the consent by both the individual taking part, and the person who presented and obtained the informed consent. The person who takes consent will be suitably qualified and experienced, and will have been authorised to do so by the Chief/Principal Investigator as detailed on the Delegation of Authority and Signature log for the study.

The original signed consent forms will be retained at each study site within the Investigator Site File (ISF) together with a copy of the relevant information sheet. A copy of the signed Informed consent will be given to participants a copy retained in the participant medical notes, and a copy retained for sample transfer.

8.4 Screening post consent

A two-tiered screening approach will be implemented following informed consent to ensure accurate identification of sarcopenia, particularly in the lower limbs. This approach addresses the limitation of using handgrip strength alone, which may not adequately reflect lower limb sarcopenia, especially in dialysis patients. Both of these tests feature in the guidance of the diagnosis of sarcopenia as defined by the EWGSOP2.

An inclusion criterion is the presence of sarcopenia. Eligibility will be determined by either:

- (i) Low muscle strength measured using a hand grip dynamometer (<27kg men and <16kg women), **OR**
- (ii) Sit to Stand 5 score (>15 seconds for both men and women) **if handgrip strength exceeds the sarcopenia threshold.**

The screening procedure will follow these steps:

- 1) All participants will first undergo handgrip strength testing.
- 2) Participants who meet the threshold for low muscle strength will be deemed eligible and will proceed to randomisation.
- 3) Participants who exceed the handgrip threshold (i.e., do not meet the low strength criterion) will then perform the Sit to Stand 5 test.
- 4) Participants with a Sit to Stand 5 time >15 seconds will also be considered eligible and proceed to randomisation.
- 5) Participants who do not meet either criterion ((i.e., have normal handgrip strength and Sit to Stand 5 time ≤15 seconds) will not be eligible and will not enter the study.

As part of the Patient and Public Involvement work that we carried out prior to grant submission, patients suggested to include an opportunity to try the NMES procedure before they are randomised to see how well they are able to tolerate it. For those patients that are eligible, they will be offered the opportunity to try NMES on one occasion. The researcher will talk them through the procedure and explain which parameters will be changed and give the opportunity to control the different parameters to see how they find it. If patients do not think they will be able to tolerate the NMES they can withdraw from the study before they are randomised. As part of the screening visit, we will also familiarise people with the isometric strength measurement, our primary outcome measurement. This is to ensure they are able to complete this assessment with no problem and to eliminate any learning effects in the assessment visit.

8.5 Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies

Not applicable for this study.

8.6 Randomisation

After providing written informed consent and successfully completing the sarcopenia screening, participants will be randomised by a delegated individual at each participating centre to either the intervention (3-months (12-weeks) of NMES) or the control group (standard care) in a 1:1 manner. Participants will be allocated using minimisation factors of age (<60 years and ≥ 60 years), time on dialysis (<1 year and ≥ 1 year), and site (dialysis unit); this will ensure the external validity of the results. Randomisation results will be revealed to the designated researcher after baseline measurements have been collected.

Each participant will be given a unique participant ID number at randomisation. This participant ID number will be used to identify the individual participant throughout the study and will not be re-assigned to any other participant. Due to the nature of the intervention, blinding of the participants and the study team to the randomisation arm is not possible.

Randomisation will be performed using a validated web-based system to maintain allocation concealment. This will be managed by the Leicester Clinical Trials Unit.

8.7 Baseline data

These assessments can be split over multiple visits if the participant wishes.

1) Demographic and clinical information:

Date of birth/age, gender at birth, ethnicity, medical history and medications will be collected from hospital records.

2) Hand Grip Strength

Participants will perform this assessment seated with their feet flat on the floor, or standing if participant cannot be seated, using the non-fistula arm. Participants will be asked to squeeze the handheld dynamometer as hard as they can on three occasions with a short rest in between. The highest measurement will be taken.

3) Isometric strength and rate of force development

Participants will be seated in a custom-built dynamometer, with their lower leg secured to a brace in series with a strain gauge force transducer. Following a series of warm-up contractions of gradually increasing force, participants will perform a series of 3-4 brief maximum voluntary contractions lasting ~5 s and separated by ~1 minute of rest, attempting to exert as much force as possible during each contraction. After that, participants will perform 10 efforts of contracting "as fast and as hard as possible" for ~1 s to at least 80% of maximal force (separated by 30-45 seconds of rest) to allow assessments of the rate of force development.

4) Quadriceps Cross-sectional area and architecture

Measures will be taken at mid-point of the thigh, and three measures (within 10%) of rectus femoris cross sectional area will be taken and the mean recorded. Images of the quadriceps will be taken (pseudonymised) for later analysis of grayscale (muscle quality). Muscle thickness and angle of pennation will also be measured by ultrasound at points along the quadricep.

5) Short Physical Performance Battery

This involves 3 successive balance tests, side by side stand, semi tandem stand, and full tandem stand, a gait speed test and sit to stand 5 test.

Balance tests

The participant is asked to stand unsupported for 10 seconds with their feet in a certain position (feet together, semi tandem, full tandem). The length of time they are able to remain balanced for in seconds is recorded.

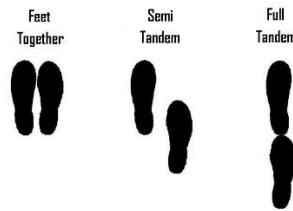


Figure 2: Image of three foot positions during the balance tests

Gait Speed

The participant walks between two timing gates or cones at their usual walking pace placed 4m apart. Speed in m/s is recorded.

Sit to Stand 5 test

The participant starts from a seated position on a hard, upright chair (such as a dining chair), with the feet flat on the floor and the knees bent at 90°. For the test, the participant simply stands up fully and then sits down again to the starting position, without using the hands (one cycle). The length of time in seconds that it takes for the individual to complete 5 repetitions is recorded.

6) Six-minute walk test

Cones are placed up to 10-30m apart (depending upon space available) and the individual is asked to walk as far as they can in 6 minutes. Distance walked in meters is recorded.

7) Incremental shuttle walk test (ISWT)

The participant walks a level 10m shuttle course at a speed controlled by an external audible bleep signal. The bleep speed progressively increases at 1 minute intervals for a total of 12 stages, and the test is terminated when the participant fails to complete the shuttle course in the allowed time, or reaches volitional exhaustion. We may also ask participants to wear the accelerometer during this test (see section below on accelerometry).

8) Bioelectric Impedance Analysis (BIA)

BIA analysis will be carried out using a portable BCM (Body Composition Monitor). This is a painless, non-invasive method for measuring fat and fat free mass. Participants will lie in a supine position with their arms and legs slightly spread apart. Pre-gelled adhesive electrodes will be placed on the wrist and hand, as well as the ankle and foot. The procedure takes around two minutes.

9) Accelerometry

Participants will be asked to wear an accelerometer on their non-dominant wrist for 24 hours/day for 8 days. The participant does not have to do anything with the device apart from wearing it, and once it is fitted on the day of the appointment, it will not need to be removed until the wear period is over. Participants will be asked to return the watch at their next study appointment or hospital visit. Data captured by these devices will allow assessment of physical activity levels and patterns, sedentary time and sleep. Participants will also complete sleep diary over the course of 8 days to complement the data from the accelerometer. Using the diary, participants will record the time they went to sleep, and the time they woke up. Naps will not be recorded. Participants will be given two instruction documents; one containing accelerometer wear instructions and another containing instructions for completing the sleep diary.

10) Questionnaires

Participants will be asked to complete the Kidney Disease Quality of life Tool Short Form (KDQoL-SF), EQ-5D-5L questionnaire, SONG-HD questionnaire, the SARC-F questionnaire, GP Physical Activity questionnaire, the SarQoL questionnaire and a resource use questionnaire, which will be combined into one survey pack. The EQ-5D-5L and resource use questionnaire will capture the data needed to perform the health economic evaluation. To minimise recall bias, participants will be offered a resource use diary in which to record their healthcare visits and other related resource use and expenditure to aid completion of the aforementioned self-completed questionnaire. This will be optional.

11) Blood sample:

Up to 40ml (approximately 3 tablespoons) venous blood sample will be taken from the arterial dialysis line within the first hour of dialysis. Plasma/serum will be separated and stored at -80°C before the analyses described below.

Samples will be analysed/used for some or all of the following:

- Markers of metabolism and homeostasis
- Inflammatory markers and immune cell function/activation
- Biomarkers of cardiovascular risk
- Endothelial damage
- Oxidative stress
- Anabolic/catabolic hormones
- microRNA and full RNA expression
- Small extracellular vesicles isolation (exosome/microparticle)
- Genetic analysis (with relevant clause in the consent form)
- Pre-conditioning of cells *in vitro*
- Isolation of peripheral blood mononuclear cells (PBMCs)

8.8 Work Package 4: Optional mechanistic study

Optional mechanistic outcomes will be performed in a sub-group (both study arms) to assess the mechanistic effects of neuromuscular electrical stimulation on skeletal muscle morphology and function in haemodialysis patients. Participants will indicate via the consent form whether or not they wish to participate in the following optional assessments. Participants can still take part in the main study without completing these assessments. Participants may choose to take part in all, some, or none of the optional assessments, and their involvement in the main study will not be affected by their decision. These assessments will be performed in centres with appropriate capability and capacity, at baseline and at 3-month follow-up only. These are optional procedures and will only be done in some centres.

1. Skeletal muscle biopsy using the needle biopsy procedure

Both groups will undergo two muscle biopsies, one at baseline before the 3-month (12 week) period starts and a second at the end. The biopsy sample will be collected using the needle biopsy technique.

A muscle biopsy of the vastus lateralis (quadriceps), or another appropriate muscle will be taken using the needle biopsy procedure. With the participant lying supine, the skin of the thigh is sterilised using either chlorhexidine or iodine solution and anaesthetised using 1% lidocaine injected subcutaneously as local anaesthetic. A small incision (<0.5cm) is then made through the skin, subcutaneous fat and muscle fascia at a mid-thigh and lateral position. Through this incision a 12-gauge single use microbiopsy needle is inserted and a small sample of muscle (approx. 100mg) taken. Depending upon the amount of tissue collected additional passes may be required at the same site using the same incision. A steristrip and a bandage are then applied. The whole procedure takes about 15 minutes, and has been used successfully in our previous studies, which was well-tolerated (ExTra CKD ref 13/EM/0344, Explore CKD Ref 15/EM/0467). The administration of local anaesthetic may cause mild discomfort, and there is a small risk of haemorrhage or infection at the site of the biopsy. Following the local anaesthetic, the procedure is not painful, though the site of the biopsy may ache for a day. Analgesia will be offered following the procedure. All biopsies will be performed by trained healthcare professional and had experience of the procedure.

The muscle samples will be analysed for some or all of the following:

- Markers of metabolism and homeostasis
- Muscle morphology/anatomical structure/fibre type
- Protein turnover (protein synthesis and degradation) and events leading to this
- The process of myogenesis (muscle repair and regeneration)
- Neuromuscular function
- Intramuscular inflammation and processes relating to this
- Mitochondria number/function and processes relating to this
- Amino acid content and transport
- RNA and microRNA expression

1. Surface Electromyography (EMG)

Following preparation of the skin, high density grid electrodes will be placed over the surface of the thigh muscles, prior to the following voluntary muscle contractions below. The EMG grid facilitates recording of muscle electrical

activity and subsequent decomposition enables the behavior (recruitment and discharge rate) of individual motor units to be discerned. This technique has been used several times before in clinical populations with no adverse effects (IRAS ID's: 22569, 306712, 321959). Using the same dynamometer as for the isometric strength exercise, participants will complete a series of gradual sub-maximum contractions, by following a target line on the screen to achieve specific sub-maximum contraction levels.

2. Intramuscular Electromyography

The needle insertion location over the vastus lateralis muscle will be identified and cleansed, before insertion of a 26-gauge needle into the leg, ~20-40mm below the surface and into the vastus lateralis muscle. Then whilst the participant is sat on the same isometric dynamometer, participants will complete a further series of low-level gradual sub-maximum contractions.

3. Femoral nerve stimulation

Electrodes will be placed in the femoral triangle just medial of the inguinal ligament and at the top of the femur in order to evoke contractions in response to percutaneous stimulation of the femoral nerve. With participants seated on the same isometric dynamometer, the intensity of stimulation of the femoral nerve will be individualised by gradually increasing the current until a plateau in the evoked twitch response is detected (or the individual's tolerance level is reached, whichever occurs sooner). Then three identical measurement stimulations will be delivered at rest, separated by ~15-20 seconds.

8.9 Neuromuscular electrical stimulation (NMES)

Participants randomised to the NMES group will receive NMES at each dialysis session they receive for 3-months (12 weeks). It will be administered using a commercially available 4-channel portable stimulator with participants either sitting or lying down with their legs positioned over a foam wedge (or similar alternative) to increase the joint angle and stimulation efficacy, and enhance comfort. This will normally occur during the first hour of dialysis, when the participant is feeling less fatigued. The skin will be cleaned and then electrodes will be placed upon the thigh muscles. The participants will have control of the NMES device on which they will be able to change the current that is administered. During the first two to three sessions participants will be encouraged to find their initial comfortable level of stimulation intensity (the current) and to get used to how it feels. After the first week the training will be progressed by two methods:

1. Increasing session duration up to a maximum of 30 minutes, if this is not initially achievable (excluding warm up and cool down)
2. Increasing stimulation intensity (current) which determines the strength of the muscle contraction that is induced and therefore how uncomfortable it can feel.

Participants will be encouraged to increase the stimulation intensity beyond their initial comfortable level for a portion of each session. As participants become increasingly familiar with NMES and as they adapt they will be encouraged to progressively increase the stimulation intensity further. This progression will also be guided by their individual rating of perceived exertion (RPE). RPE is a scale that guides exercise intensity. Participants will be familiarised with this in the first few NMES sessions. Participants will be encouraged to achieve a of about '4' or 'somewhat' hard. In addition, a discomfort scale will be shown to the participants to help ensure the stimulation intensity is at the correct level. Exercise intensity will be monitored through a session by measuring blood lactate at the end of the session (excluding home dialysis patients due to logistical constraints). This will be performed weekly to more closely monitor progress.

Blood lactate testing: This will be performed at the end of the NMES session using the needle prick technique. Briefly, the skin on the finger (any finger can be used, but preferably the index finger) is cleaned and a single use finger prick needle (like the ones used by diabetics for blood glucose monitoring) is used to punch a small hole in the skin. Blood is absorbed onto a lactate strip and entered into the hand-held analysis device.

Every NMES session will be preceded with and followed by a cool down each of 5-minutes duration that will involve a progressive ramp-up/ ramp-down in stimulation intensity up to about '4' or 'somewhat' hard on the RPE scale, and the cool down vice versa.

8.10 Follow-up assessments

All outcome assessments made at baseline will be repeated at -3, -6 and -9-months post randomisation with the exception of the optional outcome measures which will be performed at baseline and -3 months only.

8.11 Patient Reported Outcome Measures

Questionnaires

Participants will be asked to complete the KDQoL-SF, EQ-5D-5L questionnaire, SONG-HD questionnaire, SARC-F questionnaire, GP Physical Activity questionnaire, SarQoL questionnaire, and a resource use questionnaire, which will be combined into one survey pack.

8.12 Expenses and benefits

Participants will not be paid for their involvement in the study. However, if visits are required that are not part of their normal care their travel expenses will be reimbursed at the usual NHS rate of 45p/mile up to the value of £60 per visit. If a participant requires a taxi, then this can be arranged.

8.13 Work Package 3: Health Economic Evaluation

Renal replacement therapy (dialysis and transplantation) is needed by 64,000 people in the UK alone and has a high cost, consuming 1-2% of the NHS budget (56). These high costs necessitate complex economic modelling of renal interventions which alter quality of life, clinical outcomes, dialysis setting and cost, both within and beyond the study. There are no existing health economic evaluations of neuromuscular electrical stimulation programmes in this or any other cohort of patients with long-term health conditions and as the implementation of any such intervention requires institutional support from dialysis providers; providing evidence that such schemes are cost-effective is therefore crucial (57).

8.13.1 Data sources

Resource use, and expenditure data will be collected from a participant self-completed questionnaire at baseline, 3-months, 6-months and 9-months as well as routine clinical databases (UK Renal Registry (UKRR)). To minimise recall bias, participants will be issued with diaries in which to record their healthcare visits and other related resource use and expenditure to aid completion of the aforementioned self-completed questionnaire. This diary will complement the self-completed questionnaire that participants will complete at baseline, 3-months, 6-months and 9-months. Data collected will focus primarily on healthcare-related, NHS costs (i.e. hospital admissions and length of stay, visits to and from healthcare professionals, medication) with a secondary focus on the perspective of patients and carers (i.e. changes in employment, leisure activities and unpaid care of others due to dialysis, associated travel and intercurrent illness). Resource use data will be combined with unit costs using standard validated tools (18-20) to obtain a cost per patient. To validate the healthcare resource use and expenditure data collected from participants, responses for a sample of participants will be compared to routine clinical data from healthcare secondary care records. We will obtain data on set-up and ongoing staff and resource expenditure from participating sites related to the delivery of the intervention (e.g. NMES consumables, any additional staff time, lengthening of dialysis visit etc.).

Calculation of Quality Adjusted Life Year (QALY): The EQ-5D-5L will be used to determine health state descriptions for the five components (mobility, self-care, usual activities, pain / discomfort and anxiety/discomfort) at baseline, 3-, 6- and 9-months and utility values calculated. Utility scores will be derived from participant responses to the EQ-5D-5L at baseline and 1-, 3- and 6- months. UK utility values will be derived using the approach recommended by NICE, which is currently using the validated mapping function from the existing EQ-5D-3L. These will be used to form Quality Adjusted Life Year (QALY) profiles over the 6-month period, adjusting for any imbalances in baseline EQ-5D-5L scores(21).

8.13.2 Cost effectiveness analysis

The difference in resource use, costs and quality adjusted life years (QALY) between the intervention and control arms will be calculated. An intention to treat and per-protocol analysis will be performed (the latter informing the beyond trial model below). This will reflect set-up and per session costs, ultimately reporting the cost per QALY gained; that is, the ratio of the change in costs to the change in QALYs between the 2 groups. Study results will be extrapolated to explore the potential costs and effect over the longer-term.

8.14 Withdrawal criteria

It will be clearly stated in both the PIS and the consent form that the participant is free to withdraw from the study at any time for any reason without prejudice to future care, and with no obligation to give the reason for withdrawal. If a participant withdraws from the study, or loses capacity to consent, data and samples that have been collected up until the point of withdrawal/loss of capacity will be retained and used in the study.

8.15 End of study

The end of the study will be defined as the point at which all data has been collected and analysed.

9. STORAGE AND ANALYSIS OF CLINICAL SAMPLES

9.1 Arrangements for sample collection

Plasma collection

Venous blood collected from the dialysis line from will be collected into a tube containing EDTA or sodium heparin, centrifuged at 1500g for 10 minutes at 4°C. The resulting plasma will be stored at -80 °C in 1ml aliquots. Samples will be analysed at the University of Leicester or Loughborough University.

Serum collection

Venous blood collected from the dialysis line from will be collected into plain tubes and left at room temperature for 10 minutes to clot. The sample will then be centrifuged at 2500g for 15 minutes at room temperature. The resulting serum will be stored at -80 °C in 1ml aliquots. Samples will be analysed at the University of Leicester or Loughborough University.

Peripheral mononuclear blood cell (PBMC) collection

PBMCs will be isolated from whole blood using the Ficoll-Paque Density Centrifugation method. Isolated PBMCs will be stored at -80 °C until needed. Samples will be analysed at the University of Leicester or Loughborough University.

Skeletal muscle biopsies

Muscle biopsy samples (approx. 100mg) will be treated depending upon the downstream analysis. A portion of the tissue will be immediately be stored in liquid nitrogen, in RNase later at -80°C, in electron microscopy fixative, glutaraldehyde, or placed in frozen in chilled isopentane and subsequently stored in liquid nitrogen or embedded in resin. Samples will be analysed at the University of Leicester or Loughborough University.

9.2 Arrangements for sample analysis

Plasma and serum samples will be analysed locally at the University of Leicester, or Loughborough University. We may require samples to be sent to a commercial company for more detailed analysis of proteins (e.g. cytokines) that we are unable to perform in house.

Skeletal muscle samples will be analysed locally at the University of Leicester, or at Loughborough University. If samples are to be sequenced for RNA or microRNAs, this will be performed by a commercial company.

If any sample remains after analysis has been completed and the individual has consented to their samples being retained, we will continue to store the sample for use in future studies that gain ethical approval or enter the sample into a tissue bank. A clause will be added into the consent form to this effect. If participants do not consent to this, any remaining sample will be destroyed after analysis. Samples may be analysed straight away, or stored appropriately until analysis at a later date.

9.3 Storage arrangements for samples

Samples will be stored in laboratories at the University of Leicester and Loughborough University. Samples will be placed under storage conditions as soon as possible after collection. Samples will be stored at each site and transferred to the relevant laboratory in batches every 3-4 months.

With participants' consent, samples remaining following analysis will be retained for future research and following closure of the study, will be transferred to a registered research tissue bank.

9.4 The destruction arrangements for samples

With participants' consent, any tissue remaining at the end of this study will be transferred to a tissue bank. If participants do not consent to this, any remaining samples will be destroyed under witness at a local incineration facility. Any sample destruction will be carefully documented.

It is the responsibility of the study site to ensure that samples are appropriately labelled in accordance with the study procedures to comply with the Data Protection Act. Biological samples collected from participants as part of this study will be transported, stored, accessed and processed in accordance with national legislation relating to the use and storage of human tissue for research purposes and such activities shall at least meet the requirements as set out in the 2004 Human Tissue Act.

10. SAFETY REPORTING

10.1 Definitions

Term	Definition
Adverse Event (AE)	Any untoward medical occurrence in a patient or clinical investigation participants, which does not necessarily have to have a causal relationship with this treatment. An AE can therefore be any unfavourable and unintended sign (including an abnormal laboratory finding), symptom or disease temporally associated with the study, whether or not considered related to the study.
Adverse Reaction (AR)	An untoward and unintended response in a participant to an investigational medicinal product which is related to any dose administered to that participant. The phrase "response to an investigational medicinal product" means that a causal relationship between a trial medication and an AE is at least a reasonable possibility, i.e. the relationship cannot be ruled out. All cases judged by either the reporting medically qualified professional or the Sponsor as having a reasonable suspected causal relationship to the trial medication qualify as adverse reactions. It is important to note that this is entirely separate to the known side effects listed in the SmPC. It is specifically a temporal relationship between taking the drug, the half-life, and the time of the event or any valid alternative etiology that would explain the event.
Serious Adverse Event (SAE)	A serious adverse event is any untoward medical occurrence that: • results in death • is life-threatening • requires inpatient hospitalisation or prolongation of existing hospitalisation • results in persistent or significant disability/incapacity • consists of a congenital anomaly or birth defect Other 'important medical events' may also be considered serious if they jeopardise the participant or require an intervention to prevent one of the above consequences. NOTE: The term "life-threatening" in the definition of "serious" refers to an event in which the participant was at risk of death at the time of the event; it does not refer to an event which hypothetically might have caused death if it were more severe.
Serious Adverse Reaction (SAR)	An adverse event that is both serious and, in the opinion of the reporting Investigator, believed with reasonable probability to be due to one of the trial treatments, based on the information provided.
Suspected Unexpected Serious Adverse Reaction (SUSAR)	A serious adverse reaction, the nature and severity of which is not consistent with the information about the medicinal product in question set out in the reference safety information: • in the case of a product with a marketing authorisation, this could be in the summary of product characteristics (SmPC) for that product, so long as it is being used within its licence. If it is being used off label an assessment of the SmPCs suitability will need to be undertaken. • in the case of any other investigational medicinal product, in the investigator's brochure (IB) relating to the trial in question

10.2 Reporting procedures for Adverse Events

Common non-life-threatening symptoms such as constipation, diarrhoea, colds, headache, etc. do not need to be reported for this study. Only adverse events **causally related** to the study procedures will be recorded and captured on the Adverse Events log within the participants' CRF. The following information will be recorded: description, date of onset and end date, severity, assessment of relatedness to study, other suspect device and action taken. Follow-up information should be provided as necessary. The relationship of AEs to the study will be assessed and signed off by a medically qualified individual who has been delegated the duty on the study Delegation of Authority and Signature Log.

AEs considered related to the study will be followed until resolution or the event is considered stable. All related AEs that result in a participant's withdrawal from the study or are present at the end of the study, will be followed up until a satisfactory resolution occurs.

It will be left to the investigator's clinical judgment whether or not an AE is of sufficient severity to require the participant's removal from treatment. A participant may also voluntarily withdraw from treatment due to what they

perceive as an intolerable AE. If either of these occurs, the participant must undergo an end of study assessment and be given appropriate care under medical supervision until symptoms cease or the condition becomes stable.

The severity of events will be assessed on the following scale: 1 = mild, 2 = moderate, 3 = severe.

10.3 Reporting Procedures for Serious Adverse Events

It is expected that participants will experience a significant number of underlying health conditions and consequently an increased number of expected hospital admissions. In addition, as this is an interventional study, expected events may occur related to the NMES intervention. NMES induces a muscle contraction via the delivery of a small electrical current. This may cause the muscles to feel sore the next day. There have been several previous studies of NMES in chronic disease patients, including haemodialysis patients that have reported very low rates of SAEs. A recent systematic review and meta-analysis performed by NICE has concluded NMES is safe to use in chronic disease population. Events may also be associated with the more invasive outcome measures such as the skeletal muscle biopsy and intramuscular electromyography. The muscle biopsy technique has been used successfully in many of our previous studies (REC ref: 13/EM/0344) and was well tolerated. The administration of local anaesthetic may cause mild discomfort, and there is a small risk of haemorrhage or infection at the biopsy site. Following the local anaesthetic, the procedure is not painful, though the biopsy site may ache for a day. Analgesia will be offered following the procedure. All biopsies will be performed by a doctor who is trained and has experience of the muscle biopsy procedure.

Therefore, only SAEs that are **clearly related** to the study procedures/intervention and of a **serious nature** will be subject to **expedited reporting to the Sponsor**. These SAEs include:

- Musculoskeletal injury as a direct result of the outcome assessments, skeletal muscle biopsy procedure, EMG, or the intervention (NMES)
- Anything else in the investigator's opinion that is related, serious, and unexpected.

These SAEs, occurring from the time of randomisation until end of assessment period, will be reported to the Sponsor immediately and within 24 hours of becoming aware of the event. The following information will be collected:

- full details in medical terms and case description
- event duration (start and end dates, if applicable)
- action taken
- outcome
- seriousness criteria
- relationship to the study procedure or intervention

All other SAEs will be recorded using the SAE Log CRF. SAE data will be recorded on the REDCap database at regular intervals so that the LCTU can generate up-to-date reports for DSMC meetings. The DSMC will review the listings for clinical relevance and advise the TSC and Sponsor on the suitability of the continuance of the study following their review of the ongoing safety data and whether any further data should be collected or additional analyses undertaken.

Deaths will be recorded as part of the study outcomes and therefore **will not** be subject to expedited reporting.

SAEs will be reported using appropriate forms and according to the Sponsor SOP for reporting serious adverse events. Additional information will be provided if requested to the Sponsor and main Research Ethics Committee (REC). The Principal Investigator or another delegated physician (as agreed by the Sponsor) is responsible for the review and sign off of the SAE and the assessment of causality (i.e. whether an event is related to a study procedure or intervention).

The Sponsor will perform an initial check of the information and ensure that the SAE line listing is reviewed by the Director of Research & Innovation. All SAE information must be recorded on an SAE form and sent to the Sponsor. Additional information received for a case (follow-up or corrections to the original case) needs to be detailed on a new SAE form and sent to the Sponsor.

Copies of all documentation and correspondence relating to SAEs will be stored in the TMF and/or ISF.

Any change of condition or other follow-up information should be emailed to the Sponsor as soon as it is available or at least within 24 hours of the information becoming available. Events will be followed up until the event has resolved or a final outcome has been reached.

All SAEs will be tabulated and summarised by treatment group, according to system organ class and preferred term, as classified in the Medical Dictionary for Regulatory Activities (MedDRA). No formal statistical testing will be performed. All events will be summarised by seriousness, expectedness and relatedness.

The Sponsor will report all SUSARs to the Research Ethics Committee concerned. Fatal or life-threatening SUSARs must be reported within 7 days and all other SUSARs within 15 days. The CI will inform all investigators concerned of relevant information about SUSARs that could adversely affect the safety of participants.

10.4 Reporting Urgent Safety Measures

If any urgent safety measures (USM) are taken, the CI/delegate shall immediately, give written notice to the Sponsor and the relevant REC of the measures taken and the circumstances giving rise to those measures. The CI/delegate must inform all Principal Investigators at participating sites of the USM immediately, or within 3 days from the date the measures were taken. The CI/delegate will document this in accordance with the University of Leicester's SOP for Urgent Safety Measures.

11. STATISTICS AND DATA ANALYSIS

11.1 Sample size calculation

No minimal clinically important difference (MCID) has been reported for muscle strength as determined by isometric dynamometry in the CKD population. However, our data have shown that a 10Nm increase in muscle strength was associated with a reduction in 3-year mortality of 5% (54). The data we have used in our sample size calculation come from the improvement in strength that has been previously reported by three previous studies of NMES in haemodialysis patients (27, 30, 33) i.e. a mean strength improvements of 21.7Nm and a mean standard deviation of 47.5Nm. A total sample size of 228 participants (114 per arm) is needed to detect a 21.7Nm (SD 47.5Nm) difference (standardised effect size of 0.46 (moderate)) in change in muscle strength between groups at 3-months with 90% power at the 5% significance level. This will also account for an expected 10% total attrition rate, based on our previous data (15).

11.2 Planned recruitment rate

Professors Burton and Dasgupta are both established investigators within their NHS Trusts; all proposed dialysis units fall in the governance of NHS Trusts where they are clinical leads. As the Chief Investigator of the CYCLE-HD study, Professor Burton oversaw recruitment of 130 participants to a 6-month dialysis-based exercise study (using cardiac MRI) at a recruitment rate of 1-2 participants per week across 3 units. Given that the intervention was more complex and of longer duration, with outcome measures more onerous to collect, we believe a recruitment rate of 2-4 participants per week over 21-months is achievable and will comfortably exceed our required sample size of 228.

11.3 Statistical analysis plan

A statistical analysis plan (SAP) will be prepared by the Trial Statisticians and will contain full details of all statistical analyses. The SAP will be agreed with appropriate oversight prior to database lock and published in a study protocol paper. Any changes to the original SAP will be detailed along with the reason(s) for changes in subsequent SAPs. No formal stopping rules or interim analyses have been pre-defined or planned.

11.3.1 Summary of baseline data and flow of participants

Some, or all of the following baseline data will be collected from all participants:

- Demographic information (e.g. height, weight, date of birth, ethnicity, gender)
- Clinical information (e.g. prescriptions, comorbidities, haemoglobin, glucose, hba1c, eGFR, WBC, Fev1)
- Isometric strength (Nm)
- Rectus femoris cross-sectional area (cm²)
- Fat mass (kg)
- Fat free mass (kg)
- Lean body mass (kg)
- Body fat (%)
- Skeletal muscle mass (kg)
- Appendicular lean mass (kg)

- Muscle thickness (mm)
- Angle of pennation (degrees)
- Distance covered during the 6-minute walk test (m)
- Hand grip strength (kg)
- Sit to stand 5 (secs)
- Balance (seconds)
- Gait speed (m/s)
- KDQoL-SF (points)
- GP-PAQ (points)
- ED-5D-5L (points)
- SARC-F (points)
- SONG-HD-fatigue (points)
- SarQoL (points)
- Motor unit recruitment and decruitment threshold (Nm)
- Motor unit discharge frequency (Hz)
- Motor unit conduction velocity (m/s)
- Motor unit potential jiggle and segment jitter (AU)
- Quadriceps twitch contractile properties (Nm)
- Quadriceps maximal M-wave (mV)

Plasma/serum samples will be analysed/used for all or some of:

- Markers of muscle metabolism/homeostasis
- Inflammatory markers and immune function/activation
- Biomarkers of cardiovascular risk
- Endothelial damage
- Oxidative stress
- Anabolic/catabolic hormones
- microRNA expression
- Exosome/microparticle isolation
- Genetic analysis

Skeletal muscle biopsy samples will be analysed for all or some of:

- Markers of muscle metabolism/homeostasis
- Muscle morphology/architecture/fibre type
- Protein turnover (protein synthesis and degradation) and events leading to this
- The process of myogenesis (muscle repair and regeneration)
- Intramuscular inflammation and processes relating to this
- Mitochondria number/function and processes relating to this
- Amino acid content and transport
- RNA and microRNA expression

11.3.2 Descriptive analysis

Data will be checked for outliers and missing values and validated using the defined score ranges for all outcome measures. Baseline data will be summarised by group to assess comparability between treatment arms, and to highlight any characteristic differences. Statistical tests for imbalance will not be carried out.

It is likely that some data may not be available due to death, kidney transplantation, and voluntary withdrawal of participants or lack of completion of individual data items. Where possible the reasons for missing data will be ascertained and reported. Although every effort will be made to minimise crossovers from both intervention arms, the numbers, direction and reasons for participants moving between arms will be recorded and reported in line with CONSORT (Consolidated Standards of Reporting Trials) guidance.

11.3.3 Analysis of primary outcome

The primary analysis will compare the change in muscle strength from baseline to 3-months (i.e. at the end of the intervention period) between randomised groups. The primary analysis will be conducted by intention to treat (ITT) comparing all those randomised to the NMES programme to those who were randomised to standard care. Linear regression with change in muscular strength as the dependent variable, adjusted for baseline value and the

minimisation factors (age, time on dialysis, site (dialysis unit)), will be used to compare treatment groups, the adjusted mean difference between the treatment arms will be presented with a 95% confidence interval.

11.3.4 Analyses of secondary outcomes

The secondary outcomes will be analysed in a similar manner to the primary outcome. All represent continuous data and therefore linear regression will be used. All analyses will be adjusted for baseline value and the minimisation factors. The number of deaths and cardiovascular events expected is relatively low, therefore formal time to event analyses will not be conducted. Kaplan–Meier will be presented to describe the relationship between these events and treatment.

11.4. Subgroup analyses

A priori sub group analysis will include, gender, age, time on dialysis, physical activity levels (i.e. sedentary versus active) and the severity of sarcopenia at baseline (i.e. probable vs severe).

11.5 Adjusted analyses

The primary analysis will be adjusted for the minimisation factors.

11.6 Interim analysis and criteria for the premature termination of the study

No criteria for early termination of the study have been set.

11.7 Participant population

We will recruit haemodialysis patients (either home or unit based) who have been receiving dialysis for more than 3 months.

11.8 Procedure(s) to account for missing or spurious data

By design there will be no missing data for the minimisation factors, if the primary outcome is missing for less than 5% of the study population at baseline and 3-months, a complete case analysis will be conducted. If there is more than 5% missing outcome data, multiple imputation will be used. The imputation will be carried out using the command MI in Stata. MI replaces missing values with multiple sets of simulated values to complete the data, performs standard analysis on each completed dataset, and adjusts the obtained parameter estimates for missing-data uncertainty using Rubin's rules to combine estimates.

12. DATA MANAGEMENT

12.1 Data Flow Diagram

This is a separate PDF document.

12.2 Data collection tools and source document identification

All physical function data will be entered into an electronic case report form (REDCap) and collated on an excel spreadsheet. All pseudonymised lab data will be collated and stored using the lab archives online database as well as in individuals' lab books. These lab books contain pseudonymised results of the experiments performed with the biological samples, the methods used and any variation of these methods and will be used throughout the study.

12.3 Source Data

Source documents collected during this study include, clinical records, completed questionnaires, and ultrasound scans. In addition, all physiological data will be entered into an electronic case report form and will also be considered as source data.

All documents will be stored safely in confidential conditions. On all study-specific documents, other than the signed consent, the participant will be referred to by the study participant number/code, not by name.

12.4 Data handling and record keeping

Each participant will be assigned a unique identification number upon consent and this will be added to all study documents/data collection tools in place of the participant's name. All study data will be entered on to paper CRFs before being entered into the REDCap database. The database will be located on a University of Leicester server.

A copy of the completed participant informed consent form and participant information sheet will be placed in the medical notes of all participants and in the Investigator Site File. A sticker will be placed on the cover of the notes (or inside cover) detailing the study title, contact details of the PI and the fact that the notes should not be destroyed

for 6 years from the end of the study. All study visits summaries and relevant SAEs will be recorded in the hospital notes.

A contacts database (containing participant contact details) will be held separately from the study database. Participants' contact details will be held securely in accordance with data protection regulations. This will be password protected and managed by the research team at each site.

All data handling and record keeping will be kept in adherence to University of Leicester's and relevant NHS Organisations' policies. All study documentation containing identifiable patient data will be managed in accordance with ICH-GCP, The UK Policy for Health and Social Care Research and the Data Protection Act.

12.5 Access to Data

Direct access will be granted to authorised representatives from the Sponsor, host institution and the regulatory authorities to permit study-related monitoring, audits and inspections in line with participant consent.

The Chief Investigator and relevant study staff will have access to the data collected as part of this research. Access to the study database will be restricted by role-based permission to authorised study personnel will be suitably trained on the system prior to being granted access. Individual user accounts will be password-protected and will not be shared between members of the study team.

12.6 Archiving

Research data and archived files will be stored for a minimum of 6 years after the study has ended. Storage will comply with the University of Leicester archiving Standard Operating Procedure. Details can be found at: <https://le.ac.uk/research/regi/standard-operating-procedures>. Destruction of essential documents will require authorisation from the Sponsor. Archiving of source data or the Investigator Site File (ISF) for participating sites will be arranged by the relevant participating site.

13. MONITORING, AUDIT & INSPECTION

The University of Leicester as Sponsor operates a risk-based monitoring programme which this study will be subject to.

14. ETHICAL AND REGULATORY CONSIDERATIONS

14.1 Research Ethics Committee (REC) review and reports

Once the initial sponsor review process is complete and a sponsor reference number has been allocated, and all requested documentation has been received and checked, authorisation from the University of Leicester's Research Governance Office will be issued to book further review of the proposed research. The University of Leicester's Ethics Committee or NHS Research Ethics Committee and the Health Research Authority will then review the proposal. Agreement in principle is subject to the research receiving all relevant regulatory permissions. Submission for regulatory approvals will be submitted via Integrated Research Application System (IRAS). The Chief Investigator will ensure that all regulatory approvals, confirmation of capacity and capability from NHS sites and sponsor greenlight are in place before participants are approached.

For any required amendments to the study, these will be submitted to the sponsor in the first instance for review and approval to submit the amendment for external regulatory approval. Amendments must be implemented following all required ethical, site and Sponsor approvals and in line with Sponsor Standard Operating Procedures. The Research Governance Office's Standard operational procedures will be followed for the duration of the study.

The Chief Investigator will notify the REC when the study has ended by completing the end of study notification form and will submit a final report of the results within one year after notifying REC.

A Trial Master File will be maintained for the duration of the study and will be stored for 6 years after the study has ended. The only time this could be exceeded, is if samples are being retained beyond the scope of the original study i.e. there is consent for future research. In this circumstance ICFs would have to be retained for as long as the samples are in existence, as we have a legal requirement to prove the samples were obtained with consent.

14.2 Peer review

Prior to review by the sponsor, the protocol has been through the external peer review as part of the grant submission process. It was externally reviewed by seven experts.

14.3 Public and Patient Involvement

Population (P): As part of other NIHR funded research within the dialysis population, we have established a national Patient Participation, Involvement and Experience (PPIE) group comprising people on dialysis and their family / carers. This group, led by our patient co-applicant (Fez Awan) have helped co-develop the research question and study design both for the stage 1 application and subsequently for this stage 2 research plan.

Research question and intervention (I): The PPIE group understood the benefits of regular exercise, but despite motivation and intention, many are unable to exercise consistently. They felt NMES might be a more realistic therapy they would be able to take part in on a regular basis. Reviewing the intervention, a number of improvements were made to the protocol:

- Inclusion (and design) of the external pilot study to assess the tolerability (Work package 1)
- To include issues of comfort (including the pad size and their placement)
- Inclusion of an adapted screening phase to allow potential participants to trial the NMES intervention before consent (and minimise attrition / drop out).
- Input into the randomisation technique (individual vs cluster) for work package 2 and then insight into mitigation strategies to prevent contamination between groups (use of curtains, additional time discussing in clinic rooms) and their acceptability to participants.
- To broaden the eligibility criteria to include home haemodialysis patients and ways to ensure participation is least intrusive to encourage enrolment.

Control (C): All patients were keen to be able to try NMES if they were in the study. However, the PPIE group provided reassurance that patients randomised to standard care would understand the importance of the randomised design (and the 50% chance of being allocated to the control group), minimising the impact of resentful demoralisation. Nevertheless, there was a clear message to ensure that the NMES device was affordable and easy to use as participants may wish to purchase their own after the study (irrespective of group allocation). This has been updated to ensure a commercially available device is used throughout.

Outcome (O): Patients highlighted muscle weakness (which makes up the principal component of the diagnosis of sarcopenia) as one of the most intrusive symptoms they experience. Following feedback from the Funding Committee, the PPIE group were pleased to include additional measures of quality of life (KDQoL-SF) as well as symptom burden (fatigue) that are known to be some of the most important outcomes to people on dialysis. The 6-month extension to the protocol to allow for this additional data collection was seen as a positive step and as with previous studies. There was no anxiety around questionnaire fatigue because the participants are attending for their treatment at that time, in any case. To ensure that the intervention is as easy to undertake by home haemodialysis patients in the community and that the outcome measures are as straightforward to collect, a number of action points were highlighted by the PPIE members:

- To ensure a systematic approach is adopted for screening that ensures people on home haemodialysis are identified
- To allow as much flexibility as possible for scheduling visits at the pre-screening and consent stage (e.g. being able to travel to the nearest dialysis unit rather than hospital centre)
- To offer easy access to remote support and regular scheduled 'check-ins' to help ensure adherence to the intervention.

14.4 Assessment and management of risk

The main risks involved in this study are:

1. Tests of physical function: As with all exercise there is a small risk of injury. All tests will be carried out by a trained member of the team and explained and demonstrated to all participants. Before the test is carried out, participants will undergo a familiarisation test where they can practice and get used to how the test feels. All the tests that we have included here are routinely used in long-term conditions, and they will all be carried out in a hospital setting.
2. NMES procedure: This evokes a muscle contraction, so it is likely that following the first few sessions especially, participants will feel sore afterwards, much like when you have lifted weights after having not done this exercise for a while. This soreness will likely last a day or two at the start of the programme, but is not due to damage to the muscle, but is the normal response to having performed unaccustomed exercise.
3. Intramuscular electromyography: Intramuscular EMG involves inserting a thin needle (similar size to acupuncture) into the muscle during low level contractions. Intramuscular EMG is a routine clinical procedure with reports of complications being very rare. The possibility of bleeding is very low, and

occasionally bruising around the insertion site is possible though rare. We have used this technique several times before in clinical populations with no adverse events (IRAS IDs: 22569, 306712, 321959)

4. Femoral nerve stimulation: stimulation of the femoral nerve can result in some brief discomfort in the area under the stimulating (cathode) electrode due to local skin receptor activation and this effect is usually perceived as a tingling sensation that accompanies involuntary muscle twitch contractions. This discomfort disappears as soon as the stimulation ceases (1 ms pulse). Participants will be monitored throughout this procedure to ensure that discomfort is not excessive. There are rare reports of the stimulation interfering with implantable devices and rare reports of skin burns; therefore, participants with a pacemaker or a similar device will be excluded.
5. Blood sampling: samples will be collected from the participants specifically for research purposes only. A 40ml / 2 tablespoon blood sample will be collected from the arterial dialysis line within the first hour of dialysis to prevent the need for additional needling over participants' direct clinical care. The procedure to collect blood for blood lactate analysis may cause some bruising of the finger tips.
6. Skeletal muscle biopsy: Participants will undergo a biopsy of the thigh muscle. The biopsies will be performed under local anaesthetic by a clinician experienced in the technique. With the participant lying supine, the skin of the thigh is cleaned thoroughly using iodine solution, and 4-5ml 1% lignocaine injected subcutaneously as a local anaesthetic. A small incision (<0.5cm) is made through the skin, subcutaneous fat and muscle fascia at a mid-thigh and lateral position. Through this incision a 12-gauge microbiopsy need is inserted and a small sample (approx. 100mg, the size of a pea) is taken. This technique has been used in our previous studies and was well tolerated (13/EM/0344; 10/H0406/50; 15/EM/0467). The administration of local anaesthetic causes mild discomfort and there is a small risk of haemorrhage or infection at the site of the biopsy. The procedure is not painful following the local anaesthetic, though the site of the biopsy may ache for a day. Analgesia will be offered following a biopsy.
7. Questionnaire burden: We are asking participants to complete seven questionnaires which will take about 75 minutes to complete. However, they are all quite short and simple to complete and participants will have the option of taking them home to either bring back on your next visit to the dialysis unit, or post them back to the research team.

14.5 Regulatory Compliance

The study will not commence until it has received a favourable opinion from REC, HRA and has been given the green light by the Sponsor.

For any amendment to the study, the Chief Investigator or designee, in agreement with the sponsor will submit information to the appropriate body in order for them to issue approval for the amendment.

14.6 Protocol Compliance

14.6.1 Protocol deviations

A study related deviation is a departure from the ethically approved study protocol or other study document or process (e.g. consent process or administration of study intervention) or from GCP or any applicable regulatory requirements. Any deviations from the protocol will be documented in a protocol deviation form and filed in the TMF/ISF as applicable. If a protocol deviation occurs, then the CI (or delegate) will document this in accordance with the University of Leicester's SOP for Identifying and Reporting Deviations and Serious Breaches of GCP and/or the Protocol. Deviations from the protocol which are found to frequently recur will be explored and where necessary an amendment to the protocol will be made.

14.6.2 Serious breaches

A "serious breach" is a breach of the protocol or of the conditions or principles of GCP which is likely to affect to a significant degree –

- (a) the safety or physical or mental integrity of the study subjects; or
- (b) the scientific value of the research.

In the event that a serious breach is suspected, the Sponsor will be contacted within one working day. In collaboration with the CI, the serious breach will be reviewed by the Sponsor, and, if appropriate, the Sponsor will report it to the approving REC and relevant NHS host organisation within seven calendar days.

14.7 Data Protection and Participant Confidentiality

All information collected in the study will be kept strictly confidential.

The Chief Investigator will be the data custodian.

The Chief Investigator and research team will comply with the requirements of the General Data Protection Regulation (and other applicable regulations) with regards to the collection, storage, processing and disclosure of personal information and will uphold the Act's core principles.

Analysis of the data generated will be undertaken by the Leicester Clinical Trials Unit on University of Leicester premises. All collected data and electronic confidential information will be held on a secure password-protected database accessible to only essential personnel at each participating site. Research data will be pseudonymised at participating sites before being transferred to the University of Leicester.

Pseudonymised research data will be stored for a minimum of six years after the study has ended, unless there is explicit consent for the data to be retained beyond the scope of the original research project, in which case it would be kept indefinitely

Consent forms, enrolment logs and details of record linkage (i.e., participant ID numbers/pseudonyms) will be kept for a minimum of 6 years after the study has ended as part of the research data so that in the event of the data being challenged, this will allow for verification of the quality of the data. At the end of this period approval from the Sponsor will be requested for the destruction of the data.

While participants are taking part in the study their contact details will be available to the researchers so that they can contact the participant to arrange the details of their research involvement. These will be deleted once they have been used for their agreed purpose. Where individuals have consented to receive a copy of the research findings, contact details will be retained until this time. Contact details will be stored securely and separately from participants' research data and clinical information.

The TMF will be kept a folder in a locked cabinet/drawer in a secured room in a secure office environment office at the University of Leicester by the Chief Investigator (or delegate). ISFs will be kept at the relevant NHS organisations and will be stored in a secure environment. Storage will adhere to each organisational policy on storage.

14.8 Financial arrangements

This study is funded by a grant from the NIHR EME programme (funder ref NIHR158852). Additional support and resources for the study will be provided by the participating Trusts and their corresponding NIHR Research Delivery Networks (RDN). The funder will be responsible for funding the study but will not be part of the study conduct, data analysis and interpretation, manuscript writing, and dissemination of results.

14.9 Indemnity

Sponsorship and insurance for study design and management will be provided by the University of Leicester. If a participant is harmed due to negligence and/or the conduct of the study, this will be covered by the local NHS Trust(s) indemnity arrangements for all participants in clinical studies. If a study participant wishes to make a complaint about any aspects of the way they have been treated or approached during the research project, the standard National Health Service complaint system will be available to them. Details of this are made available to participants in the PIS.

14.10 Post study care

Not applicable.

14.11 Access to the final study dataset

The Chief Investigator and their appointed deputies will have access to the analysed study dataset following execution of the SAP and completion of the End of Trial Report.

15. DISSEMINATION POLICY

Upon completion, the data will be analysed and disseminated at relevant national and international scientific/medical conferences, as well as patient led conferences and workshops. The data will be published in a high impact journal as well as disseminated on social media and via blogs. A video of the results will be made to increase accessibility for patients. In addition, if participants have indicated on the consent form they wish to receive a copy of the results, this will be sent to them upon study completion which will be written in collaboration with our PPIE group.

Authorship on the manuscript will be determined by the CI according to contribution to the study after discussion with the TSC, and according to the guidelines of leading medical journals. The TSC will be responsible for approval of all manuscripts arising from the study prior to submission for publication. All publications will quote the clinical study's registration number and will acknowledge the participating investigators, TSC and DSMC, LCTU, the Sponsor and the Funder. The study will be reported in line with the CONSORT statement, which is an evidence-based, minimum set of recommendations for reporting randomised trials.

Upon completion of the study, all data sets will be deposited with the University of Leicester's research database repository (<https://leicester.figshare.com>). Any sequencing work that has been carried out will be deposited with the NCBI Gene Expression Omnibus and the R and python code will be made available in github.

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17. Appendix 1 – Amendment History

Amendment No.	Protocol version no.	Protocol date	Author(s) of changes	Details of changes made
SA01	2.0	17/10/2024	Niamh Quann Dr Shaun Barber Dr Emma Watson Dr Jakob Skarabot	- Page 1 – ISRCTN study registration ID added. - Page 8 – Study summary: Age of study participants corrected from >18 years to ≥18 years. Primary outcome updated to clarify a 3-month (12-week) NMES programme. Unit of measurement (Nm) added to isometric strength (primary outcome measure). Secondary outcomes updated to clarify the version of the KDQoL to KDQoL-SF (short form). - Page 11, section 3 – Research Question/Objectives and Outcome Measures/Endpoints: objectives updated to clarify a 3-month (12-week) NMES programme. - Page 12, Measures of QoL and social function: updated to clarify KDQoL-SF will be used. - Page 13, section 3.4 – Table of endpoints/outcomes, secondary objectives: Primary outcome updated to clarify a 3-month (12-week) NMES programme. Unit of measurement (Nm) added to isometric strength (primary outcome measure). Secondary objective ‘to measure the effect of a NMES programme on QoL’ updated to clarify KDQoL-SF will be used. Timepoints of muscle quality and architecture (e.g. echo intensity and angle of pennation by ultrasound) changed from baseline, 3, 6, and 9 months to baseline and 3 months only. Unit of measurement (Nm) added to isometric strength (primary outcome measure). - Page 15, section 5 – study design: updated to clarify a 3-month (12-week) NMES programme. - Page 15, section 6.1 – Inclusion Criteria: ‘age >18 years’ corrected to ‘age ≥18 years’. - Page 15, section 6.2 – Exclusion Criteria: muscle biopsy and intramuscular electromyography specific exclusion criteria updated to clarify corticosteroids

				(previously steroids) and DVT within the last 3 months. Bioelectrical impedance specific exclusion criteria update to add ICD in addition to pacemaker. • Page 16-17, section 7.1 – Schedule of procedures – NMES group: timeline for informed consent corrected from baseline to screening. Heart rate measurement removed. Version of KDQoL clarified to KDQoL-SF. Clarification added that sub-maximum contractions (for EMG recordings) and evoked contractions (femoral nerve stimulation) will be n=25 and optional. • Page 17-18, section 7.2 – Schedule of procedures – control group: timeline for informed consent corrected from baseline to screening. Version of KDQoL clarified to KDQoL-SF. Clarification added that sub-maximum contractions (for EMG recordings) and evoked contractions (femoral nerve stimulation) will be n=25 and optional. • Page 20, section 8.6. – Randomisation: clarified that it will be a 3-month (12-week) NMES programme. Groupings for minimisation factors of age and time on dialysis clarified. Site (dialysis unit) added as a minimisation variable. • Page 21, Section 8.7 – Baseline data – Questionnaires: Clarification that the KDQoL-SF will be used. • Page 21, Section 8.7 – Baseline data – Bioelectrical Impedance Analysis (BIA). Procedure updated in line with manufacturer's guidelines and study-specific SOP. • Page 22, section 8.8 – Work package 4: optional mechanistic study: Reference to participants being asked to refrain from eating or drinking anything other than water on the morning of the biopsy removed. • Page 23, section 8.9 – Neuromuscular electrical stimulation (NMES) – reference to heart rate measurement and heart rate monitor removed. (12-
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				weeks) added after 3-months. Cool-down procedure for each NMES session clarified. • Page 24, section 8.11 – Patient Reported Outcome Measures: Clarification that the KDQoL-SF will be used. • Page 28, section 11.1 – Sample size calculation: standard effect size corrected from 0.5 to 0.46 (i.e. 2 decimal places). • Page 28, section 11.3.1 – Summary of baseline data and flow of participants: Unit of measurement for isometric strength corrected from (N) to (Nm). Clarification that the KDQoL-SF will be used. Creatinine removed from clinical information collected. • Page 30, Section 11.3.3 – Analysis of primary outcome: Site (dialysis unit) added as a minimisation factor. • Page 30, section 11.3.4 – Analyses of secondary outcomes: “All analyses will be adjusted for baseline value and the stratification factors” corrected to “All analyses will be adjusted for baseline value and the minimisation factors”. • Page 32, section 14.3 – Public and Patient Involvement – Outcome (O): Clarification that the KDQoL-SF will be used. • Page 33, Section 14.4 – Assessment and management of risk: Requirement for participants to fast for biopsy collection removed.
SA02	V3.0	31/03/2025	Niamh Quann Dr Emma Watson Prof James Burton	• Page 8, Study Summary – study participants: changed to sarcopenia diagnosed with low handgrip strength OR prolonged sit to stand score. • Page 9, Roles and Responsibilities of Trial Management Committees/Groups and Individuals: Lay representative removed from DSMC. • Page 10, Study Flow Chart: order of baseline outcome assessments and randomisation corrected. Clarifications added to indicate that WP4 outcomes will be assessed at baseline and 3 months, and WP3 data collection

				will be conducted at baseline, 3, 6, and 9 months. • Page 15, Section 6.1 – Inclusion criteria: Sarcopenia diagnosis criterion updated to include handgrip strength AND sit to stand 5. • Page 15, Section 6.2 – Exclusion criteria: Exclusion criterion 1(iii) revised to remove “claudication” and now includes “pain at rest or functional impairment that precludes completion of study assessments.” Additional exclusion criterion added: “Vascular access in the lower limbs that may interfere with intervention delivery.” Bioelectrical impedance specific exclusion criteria: the criterion “has a pacemaker or ICD” removed due to duplication in the main exclusion criteria. • Page 16, Section 7 – Study Schedule: Clarification added specifying that participants should commence the intervention within 2 weeks of randomisation. • Page 16, Section 7.1 – Schedule of Procedures: Weekly column added to capture blood lactate measurements. STS5 added to screening in addition to handgrip strength. Medical history moved under screening procedures as this won’t be collected until after screening. New line added for handgrip strength for outcome measures. Familiarisation session for evoked contractions (femoral nerve stimulation) removed. Number of skeletal muscle biopsies reduced from 3 to 2 for the NMES group, and associated footnote removed. • Page 19, Section 8.4 – Screening Post-Consent: section updated to include two-tiered screening approach (handgrip strength AND STS5). • Page 22, Section 8.8 – Work Package 4: Optional mechanistic study: additional biopsy for the NMES group removed. Clarification added that participants may choose to take part in all, some, or none of the optional assessments. • Page 23, Section 8.9 – Neuromuscular electrical
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				stimulation (NMES): additional detail has been added regarding participant positioning during NMES. Page 32, Section 14.4 – Assessment and management of risk: familiarisation session for femoral nerve stimulation removed.
SA03	V4.0	16/01/2026	Niamh Quann Dr Emma Watson Prof James Burton	- Key study contacts: Administrative updates; addition of protocol contributors. - List of abbreviations: Sit to stand 60 removed. - Section 3.3.2 – Secondary endpoints/outcomes: sit to stand 60 test (muscle endurance) removed. - Section 3.4 – Table of endpoints/outcomes: Sit to stand 60 and muscle endurance removed. - Section 5 – Study setting: Reference to specific NHS Trusts removed. - Section 6.2 – Exclusion criteria: “metallic hip or knee joint” removed. - Section 7.1 – Schedule of procedures – NMES group: sit to stand 60 removed. - Section 7.3 – Schedule of procedures – control group: sit to stand 60 removed. - Section 8.6 – Randomisation: Timeline for randomisation changes from after baseline measurements have been collected to after providing written informed consent and successfully completing sarcopenia screening. Clarification added that randomisation results will be revealed to the designated researcher after baseline measurements have been collected. - Section 8.7 – Baseline data: sit to stand 60 removed. - Section 8.9 – Neuromuscular Electrical Stimulation (NMES): Clarification added that participants can position their legs over a foam wedge or similar alternative. Clarification added that home dialysis patients will be excluded from blood lactate

				measurements due to logistical constraints. • Section 11.3.1 – Summary of baseline data and flow of participants: Sit to stand 60 removed. • Section 14.4 - Assessment and management of risk - Femoral nerve stimulation: participants with metal objects in/around the hip joint will no longer be excluded.
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